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MCDONNELL DOUGLAS

SPACE TUG SYSTEMS STUDY (CRYOGENIC)
SEPTEMBER DATA DUMP

VOLUME 3 Summary
Program Option 3

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PREPARED FOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
UNDER CONTRACT NO. NAS8-29677

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

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PREFACE

This study report for the Tug Program is submitted by the McDonnell Dougl[illegible] Astronautics Company (MDAC) to the Government in partial response to Cont[illegible] Number NAS8-29677.

The current results of this study contract are reported in eight volumes:

Volume 1 — Summary, Program Option 1

Volume 2 — Summary, Program Option 2

Volume 3 — Summary, Program Option 3

These three summary volumes present the highlights of the comprehensive d[illegible] base generated by MDAC for evaluating each of the three program options. [illegible] volume covers in summary form the applicable option configuration definit[illegible] tug performance and capabilities, orbital and ground operations, programm[illegible] and cost considerations, and sensitivity studies. The material contained [illegible] these three volumes is further summarized in the Data Dump Overview Brief[illegible] Manual.

Volume 4 — Mission Accomplishment

This volume contains mission accomplishment analysis for each of the thre[illegible] gram options and includes the tug system performance, mission capture, an[illegible] fleet size analysis.

Volume 5 — System (3 Books)

This volume presents the indepth design, analysis, trade study and sensit[illegible] technical data for each of the configuration options and each of the tug systems, i.e., structures, thermal, avionics, and propulsion. Interface [illegible] the Shuttle and tug payloads for each of the three options is defined.

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Volume 6 — Operations (3 Books)

This volume presents the results of orbital and ground operations trades a optimization studies for each option in the form of operations descriptior time lines, support requirements (GSE, manpower, networks, etc.), and resu costs.

Volume 7 — Safety (3 Books)

This volume contains safety information and data for the Tug Program. Spec safety design criteria applicable to each option are determined and potent safety hazards common to all options are identified.

Volume 8 — Programmatics and Cost (3 Books)

This volume contains summary material on Tug Program manufacture, faciliti vehicle test, schedules, cost, project management, SR&T, and risk assessme for each option studied.

These volumes contain the data required for the three options which were selected by the Government for this part of the study and are defined as:

A. Option 1 is a Direct Development Program (I.O.C.: Dec 1979). It emphasizes low DDT&E cost; the deployment requirement is 3500 pou into geosynchronous orbit, it does not have retrieval capability, it is designed for a 36-hour mission.

   MDAC has also prepared data for an alternative to Option 1 which deviates from certain requirements to achieve the lowest practica DDT&E cost.

B. Option 2 is also a direct development program (I.O.C.: 1983). It emphasizes total program cost effectiveness in addition to low DD cost. The deployment requirement is 3500 pounds minimum into geo synchronous orbit and 3500 pounds minimum retrieval from geosynch nous orbit.

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C. Option 3 is a phased development program (I.O.C.: 1979 phased to I.O.C. 1983). It emphasizes minimum initial DDT&E cost and low total program cost. The initial tug capability will deploy a minimum of 3500 pounds into geosynchronous orbit without retrieval capability, however, through phased development, it will acquire the added capability to retrieve 2200 pounds from geosynchronous orbit. The impact of increasing the retrieval capability to 3500 pounds is also provided.

CONTENTS

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INTRODUCTION

The Government's evaluation of the MDAC Tug concept selection data and recommendations presented in July 1973 resulted in the direction to conduct further in-depth analysis and to provide the resulting data and conclusions for three selected Cryogenic Tug Program options.

The material presented in this MDAC Tug Program study is completely responsive to the negotiated statement of work and subsequent direction. The study results provide a comprehensive data base that can be used in the Government planning studies to select the most attractive cryogenic Tug Program option for comparison to other alternatives under consideration. The Option 3, Phased Development Program (I.O.C. 1979 phased to I.O.C. of 1983) study results are summarized in this data package - Volume 3. Unless material herein is applicabl to both phases, there is a separate discussion of each in the appropriate sectic

The current concept evaluation process has been conducted and substantiating data for the conclusions and recommendations reached by MDAC are provided herein. Additional substantiation and detailed supporting documentation is contained in Volume 4 - Mission Accomplishment, Volume 5 - Systems, Volume 6 - Operations, Volume 7 - Safety, and Volume 8 - Programmatics and Cost; as well as in the briefing material.

A program overview has been included in Section 1 of this volume. It contains the key results of Option 3 study and a comparison of these key results with results of Option 1 and Option 2.

Section 1

PROGRAM DEFINITION AND OBJECTIVES

The Space Tug is a reusable vehicle designed to operate in conjunction wi National Aeronautics and Space Administration's (NASA's) Space Shuttle. Tug is transported by the Space Shuttle to low Earth orbit where it then forms as a propulsive stage for placement and retrieval of payloads in hi energy orbits including synchronous altitudes. When transporting the Tu payload, the Space Shuttle Orbiter is capable of deploying 65,000 lb to 160 nmi circular orbit. The Orbiter also retrieves the Tug after it per its mission from a similar orbit for return to Earth. For the purpose o system study the Tug is to be a cryogenic propulsive stage that uses liq hydrogen and liquid oxygen as propellants.

Cryogenic Tug Option 3 is a phased development program for an interim op ing capability on December 31, 1979 and a final operating capability on December 31, 1983. In developing the complete description of this progr option, the following were to be given the principal emphases:

a. Initial Tug -
   - IOC December 31, 1979
   - Minimum performance, place ≥ 3500 lb to geosynchronous
   - No rendezvous and docking ability
   - Minimum DDT&E costs, with ability to grow
   - Meet minimum payload requirements
   - 36 hour mission capability

b. Final Tug -
   - IOC December 31, 1983
   - Minimum performance, retrieve ≥ 2200 lb from geosynchronous
   - Have rendezvous and docking ability
   - Phase to emphasize low total program costs
   - Meet minimum payload requirements, provide 300 watts to PL,

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Additional groundrules assumed for the initial and final design are as follows:

a. Initial Tug -
- No multi-payload capability
- No payload spin-up capability
- Payload interface diameter fixed
- No payload checkout capability

b. Final
- Multi-mission capability with 3 payloads
- Payload spin-up capability
- Manual adjusted payload interface diameter
- Payload command checkout capability

Within Option 3 capability, two specific sensitivities were to be identif

1. Configuration and programmatic sensitivities for the Final Tug t retrieve $\geq$3500 lb from geosynchronous.
2. Programmatic sensitivity to delay both Initial and Final Tug IOC 2 years (I.O.C. December 31, 1981 and 1985).

The physical and programmatic characteristics for Option 3I and 3F are sh Table 1-1 and 1-2.

Table 1-1

PROGRAM OPTION 3 INITIAL

ILITY OPTION PHASED - DEPLOY ONLY   IOC DATE DECEMBER 31, 1979

AM OBJECTIVE MINIMIZE INITIAL DDT&E COST - DEPLOY 3,500 LB IN GEOSYNCHRONOUS ORBIT

Physical Characteristics		Program Characteristics	
		Autonomy level	IV
engine type	CAT I RL10	Development time (to IOC)	54 Mo
ture ratio	5.5:1	Mission completion probability**	0.983/0.973
ust	15,000 Lb	Fleet size	5
	441.8 Sec	Number of flights (ETR/WTR)	120/10
ype	Blowdown Mono	Reusable (ETR/WTR)	116/10
	215 Sec	Expendable (ETR/WTR)	4/0
t Summary		Ground turn around time***	19.1/19.9
n out weight	7,470 Lb	Cost Summary ($ 1973 millions)	
ss weight (less payload)	59,334 Lb	Program cost	377.26
ble propellant	51,212 Lb	DDT&E cost	190.10
age mass fraction (λ')	0.863	Peak year funding	76.7/FY '78
rmance Summary		Operations cost/flight (avg)	1.08
load deployed (geosync)	3,530	First unit cost	14.68
load retrieved (geosync)		SR&T cost	0.84
load round trip (geosync)	1,330 Lb		
tural configuration	LCT		
length	34.3 Ft		

**1.5 day mission/with kickstage

Table 1-2

PROGRAM OPTION 3 FINAL

ABILITY OPTION PHASED - DEPLOY AND RETRIEVE IOC DATE DECEMBER 31, 1983

GRAM OBJECTIVE LOW OVERALL PROGRAM COST - RETRIEVE 2,200 LB FROM GEOSYNCHRONOUS ORBIT

Physical Characteristics		Program Characteristics	
n engine type	CAT I RL10	Autonomy level	III
lixture ratio	5.5:1	Development time (to IOC)	N/A
'hrust	15,000 Lb	Mission completion probability**	0.978/0.972
SP	441.8 Sec	Fleet size	11
type	Stor Biprop	Number of flights (ETR/WTR)	188/48
SP	264 Sec	Reusable (ETR/WTR)	184/48
		Expendable (ETR/WTR)	4/0
ght Summary		Ground turn around time***	20.5/21.3
urn out weight	7,160 Lb	Cost Summary ($ 1973 millions)	
ross weight (less payload)	63,120 Lb	Program cost	470.08
sable propellant	54,661 Lb	DDT&E cost	88.82
Stage mass fraction (λ')	0.866	Peak year funding (3I + 3F)	90.2/FY 81
formance Summary		Operations cost/flight (avg)	0.72
ayload deployed (geosync)	4,350 Lb	First unit cost	17.40
ayload retrieved (geosync)	2,460 Lb	SR&T cost	13.15
ayload round trip (geosync)	1,630 Lb		
uctural configuration	ICT		
ge length	35.0 Ft		

1.1 Tug Program Overview

Each of the three tug options is discussed in a separate volume dedicated to the individual option being summarized. For the convenience of the reader, this section contains a brief program overview which presents the highlight features of all three options. Comparative data should be used with the awareness that the mission model is different for each of the options.

The following figures are individually discussed in subsequent pages.

Figure 1 -1 Space Tug Operations
-2 Key Issues
-3 Space Tug Program Options
-4 Mission Model Comparison
-5 Performance Comparison
-6 Cost Comparison
-7 Space Tug Program Option Summary Comparison

SPACE TUG OPERATIONS

This study encompasses all aspects of the Space Tug operations. Depicted the chart is the different phases of flight operations from liftoff until landing. Included is the deployment of the Tug from the Shuttle cargo ba at 160 nmi and the rendezvous of a Tug and its retrieved payload with th Orbiter before reentry and landing. Ground operations were also studied extensively.

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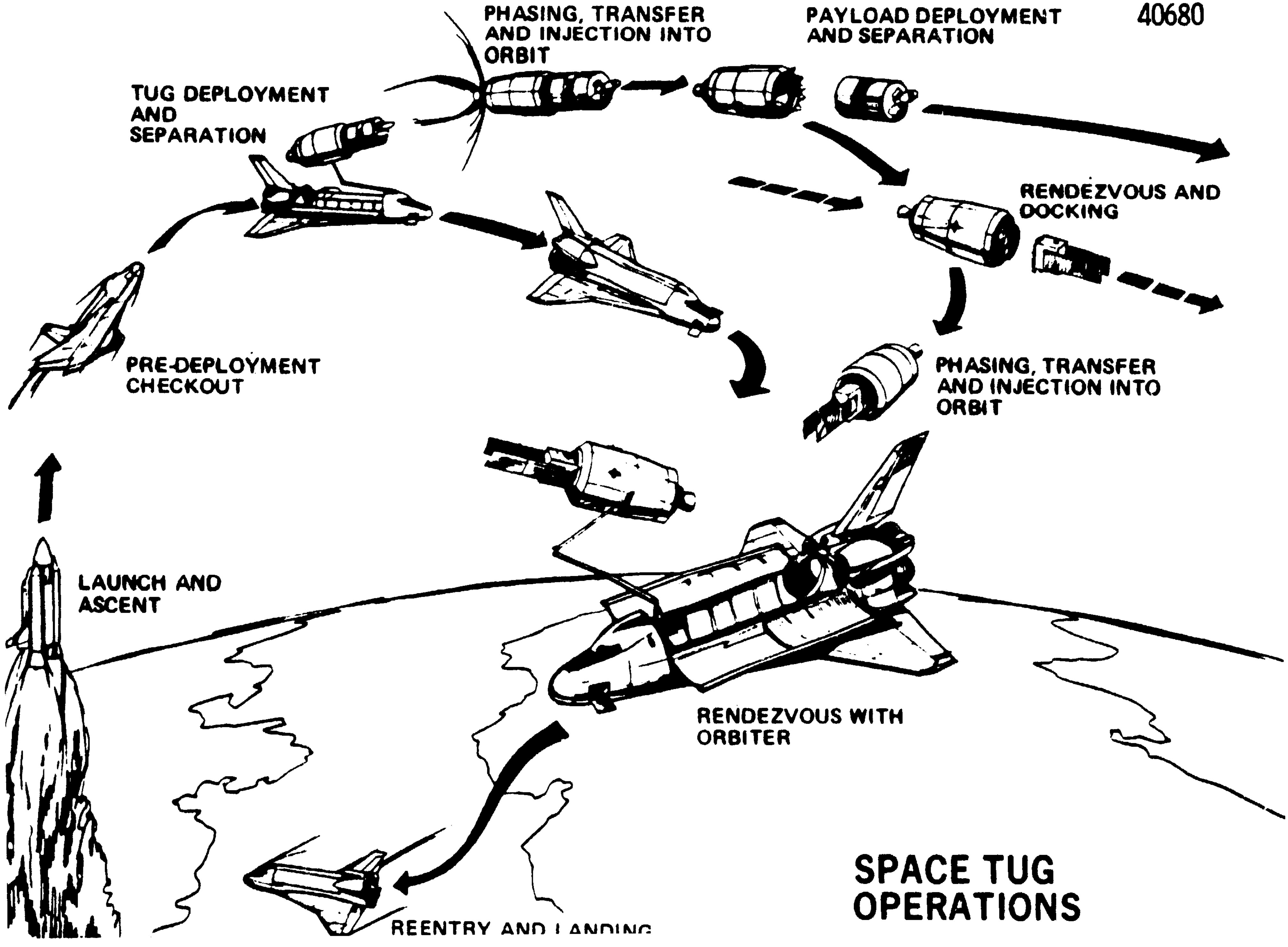

SPACE TUG OPERATIONS

KEY ISSUES

Since the Tug flies with the Orbiter during ascent and return to Earth it : meet the safety standards for a manned space vehicle during these times. performance and capability it must at least meet the minimum requirements specified by the Government. In all operations minimum DDT&E costs are important. However, DDT&E costs should not be lowered to the point that t operations cost, for the life of the vehicle, will be prohibitive. In add to minimum DDT&E and operations cost, low peak year funding is desirable, especially through the 1975 to 1978 time period.

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KEY ISSUES

- MEET SAFETY STANDARDS
- MEET PERFORMANCE/CAPABILITY REQUIREMENTS

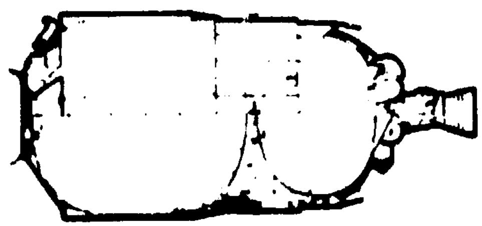
- MINIMIZE DDT&E COSTS
- MINIMIZE PEAK YEAR FUNDING
- DRIVE OPERATIONS COSTS DOWN

SPACE TUG PROGRAM OPTIONS

The three options indicated were those provided by the Government. The deployment and retrieval requirements are minimum for each option. Numer sensitivity studies were conducted for each of the options and include v ing the IOC data and assessment of program impacts.

SPACE TUG PROGRAM OPTIONS

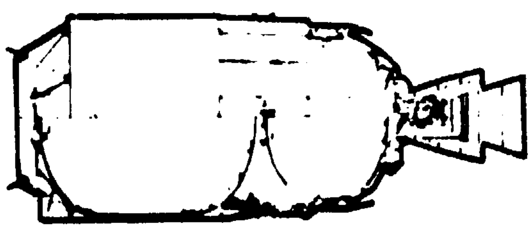
OPTION 1.
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- NO RETRIEVAL CAPABILITY
- 36 HOUR MISSION

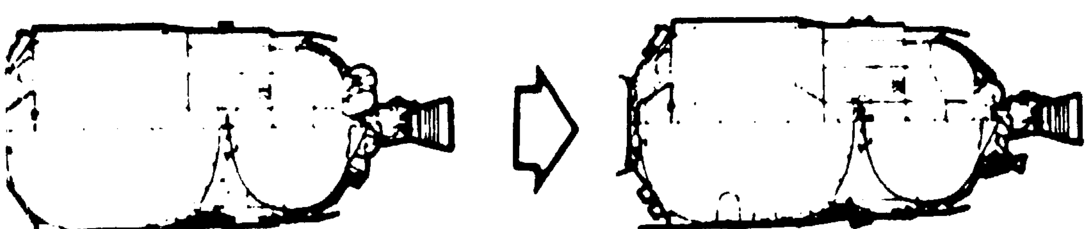
OPTION 2.
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1983

- TOTAL PROGRAM COST EFFECTIVENESS
- LOW DDT&E
- DEPLOY 3500 LB (GEOSYNCHRONOUS)
- RETRIEVE 3500 LB (GEOSYNCHRONOUS)

OPTION 3.
PHASED DEVELOPMENT PROGRAM



IOC: DEC 1979

DEC 1983

- MINIMIZE INITIAL DDT&E
- LOW TOTAL PROGRAM COST
- INITIAL:
  DEPLOY 3500 LB (GEOSYNCHRONOUS)
  NO RETRIEVAL CAPABILITY
- FINAL:
  DEPLOY 3500 LB (GEOSYNCHRONOUS)
  RETRIEVE 2200 LB (GEOSYNCHRONOUS)

MISSION MODEL COMPARISON

The mission models provided by the Government for each option different number and types of missions and the weights of the payloads involved. result of these necessary differences, care must be taken in comparing option to another. For example, in each option, the time of operation IOC to 1990 resulting in different program durations. The mission mode Option 1 contains 360 deployment missions and 4 sortie missions over an year period (1980 through 1990). The payload weights were all "current weights; the minimum in the total mission model. Of the total, 270 are synchronous or high altitude, 22 interplanetary and 68 low orbit missi

Option 2 has the heaviest payloads (using some of the low cost payload from the total mission model) and the most missions per year however th later IOC (December 1983) results in only a seven year duration. The m model includes retrieval missions as well as deployment missions. In a multiple deployment missions require a positional separation of 60° be payloads whereas the Option 1 model allowed deployment of multiple payl at one orbital location. The Option 2 model contains 437 missions (258 ments and 179 retrievals) of which 328 are geosynchronous or high altit are interplanetary and 90 are low orbit missions.

The Option 3 mission model is quite similar to the Option 2 model excep the earlier IOC (December 1979) the elimination of the retrieval missio NASA mission 5 and its decreased weight. For the years prior to 1984 (final configuration IOC date) the model is like the Option 1 model for years except for the increased payload weights. Out of 558 missions (3 deployments and 171 retrievals), 430 are geosynchronous or high orbits, interplanetary, and 106 low orbit missions.

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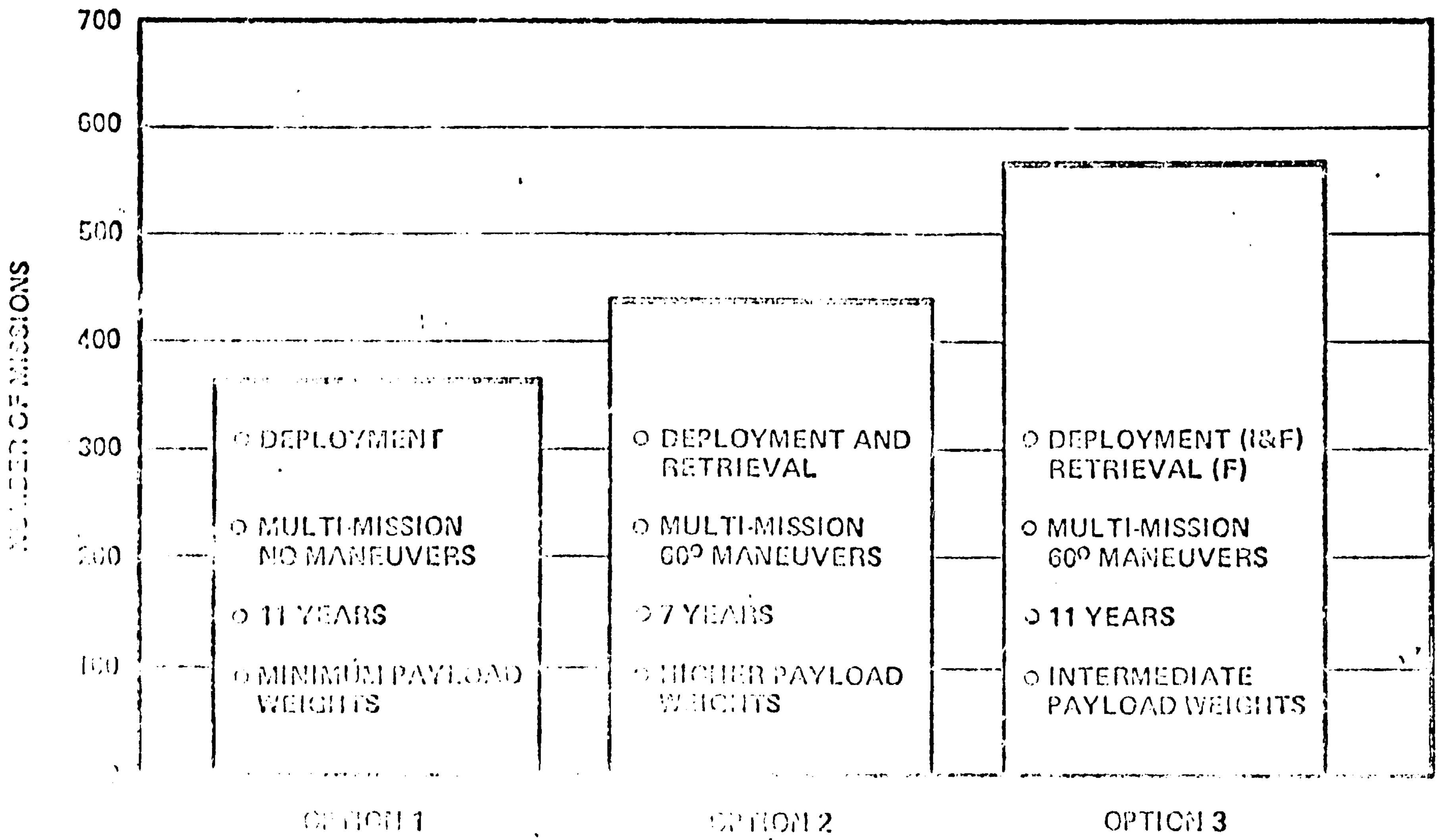
MISSION MODEL COMPARISON



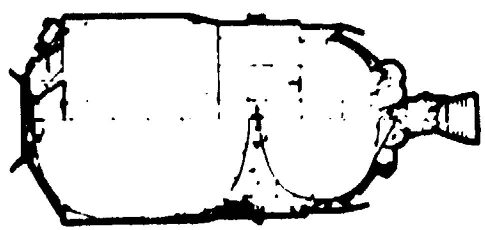
OPTION COMPARISON—PERFORMANCE

This chart compares the performance of the vehicle studies for each of the three options. In the case of Option 2 it was possible to use higher tech-nology in this vehicle because of the 1983 IOC date. Consequently, its deployment, retrieval and round trip capability far exceeds the other opti[...] It uses a Category II RL10 engine and the other vehicles have Category I RL10 engines. The final vehicle for Option 3 could be made into a vehicle with performance similar to Option 2 if the Category II RL10 engine were u[...] instead of the Category I. The deployment capability of the Option 3 In[...] vehicle and that of Option 1 are very close.

OPTION COMPARISON

PERFORMANCE

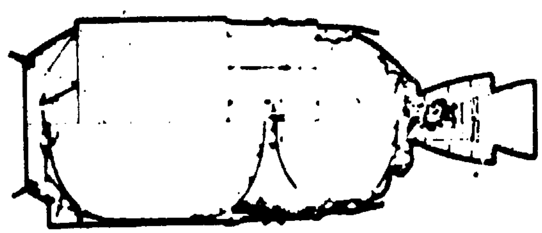
OPTION 1
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

- DEPLOY – 3,521
- RETRIEVE – NONE
- ROUND TRIP – 993

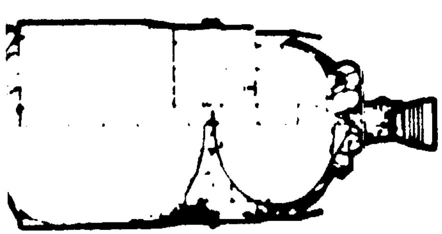
OPTION 2
DIRECT DEVELOPMENT PROGRAM



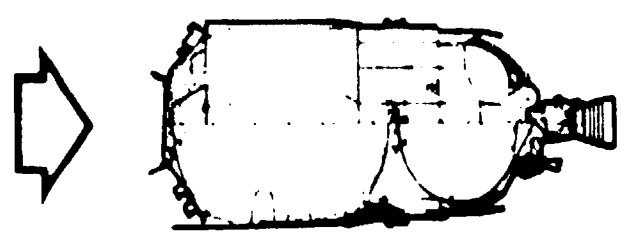
IOC: DEC 1983

- DEPLOY – 7,640
- RETRIEVE – 4,814
- ROUND TRIP – 2,953

TION 3
ASED DEVELOPMENT PROGRAM



IOC: DEC 1979



DEC 1983

	INITIAL	FINAL
DEPLOY –	3,588	4,330
RETRIEVE –	NONE	2,567
ROUND TRIP –	1,335	1,611

OPTION COMPARISON — COST

This chart provides a cost comparison breakdown of the different options costs which are strongly dependent on the mission model are specifically tified. Since the mission model must vary between options (i.e., Retrie vs Deploy only), care must be taken when comparing these costs.

An interesting comparison is the DDT&E cost for Option 1 and the DDT&E for the Initial Option 3. It should be noted that the initial phase of Option 3 is less costly than Option 1 because some of the initial GSE co for Option 3 have been deferred to final phase. This is possible becau of the limited initial fleet size. However, from a peak funding view, t initial phase of Option 3 and Option 1 are identical and peak in 1978 at 79.7 million. The total DDT&E for Option 3 is same 80 million over Opti which provides the required development for the required additional capa e.g., Retrieval, 6 days, etc. The final phase of Option 3 peaks at 90.2 lion in 1981. The advantages of the Option 3 over Option 1 is that a ph vehicle can be provided with no initial DDT&E penalty.

The higher Option 2 DDT&E cost is expected with this higher capability T The peak year funding of Option 2 occurs in 1982 consistent with the December 1983 IOC.

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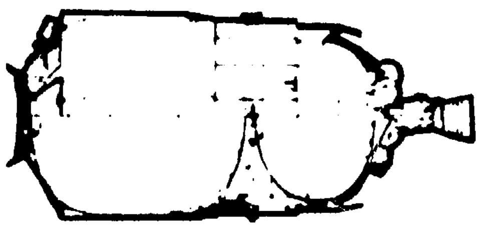
OPTION COMPARISON
COST (IN MILLIONS OF DOLLARS)

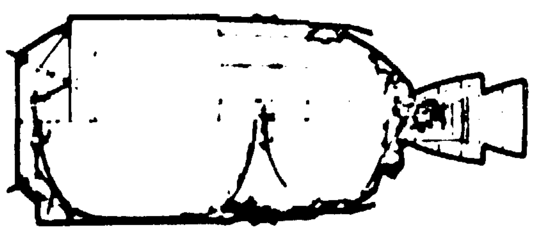
OPTION 1
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1979

• DDT&E	–	$197.1
• PEAK YEAR	–	76.7
• COST/FLT	–	0.90
• FIRST UNIT COST	–	14.4
• OPERATIONS	–	200.8
• PRODUCTIONS	–	179.6
• TOTAL PROGRAM	–	577.4

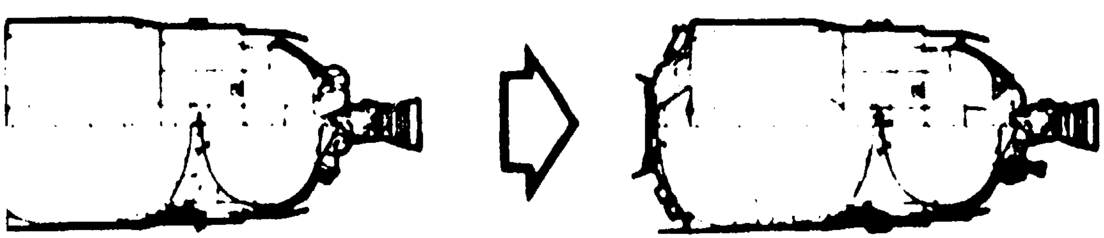
OPTION 2
DIRECT DEVELOPMENT PROGRAM



IOC: DEC 1983

• DDT&E	–	$298.8
• PEAK YEAR	–	124
• COST/FLT	–	0.76
• FIRST UNIT COST	–	18.1
• OPERATIONS	–	169.4
• PRODUCTION	–	214.3
• TOTAL PROGRAM	–	682.5

ION 3
SED DEVELOPMENT PROGRAM



IOC: DEC 1979 DEC 1983

		INITIAL	FINAL
• DDT&E	–	190.1	88.8
• PEAK YEAR	–	76.7	90.2
• COST/FLT	–	1.07	0.71
• FIRST UNIT COST	–	14.7	17.4
• OPERATIONS			
• OPERATIONS	–	88.6	204.5
• PRODUCTION	–	98.6	176.8
• TOTAL PROGRAM	–	377.3	470.1

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SPACE TUG PROGRAM OPTION SUMMARY

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CONFIGURATION DATA

OPTION NO.	1	1A	2	3I	3F	3S
N ENGINE	CAT I RL-10	CAT. I RL-10	CAT 2A RL 10	CAT I RL 10	CAT. I RL 10	CAT. 2A RL 10
TURE RATIO (EMR)	5.5-1	5.5-1	6-1	5.5-1	5.5-1	6-1
	441.8	441.8	460.2	441.8	441.8	460.2
UST	15K →	→	→	→	→	→
SSURIZATION	AMB He	AMB He	ZNPSH	AMB He	COLD. HEATED He	ZNPSH
	MONO B/D	MONO B/D	BI-PROP	MONO B/D	BI-PROP	BI-PROP
PELLANT UTILIZATION	CLOSED LOOP →	→	→	→	→	→
UMATIC BOTTLES	SIVB TITAN →	→	→	→	→	→
UCTURE CONFIGURATION	LCT	LCT	LCS	LCT	LCT	LCT
LL CONST AND MATERIAL	OPEN AL-150 →	→	GF/AL H' COMB'	OPEN AL-150 →	→	→
IK CONSTRUCTION	AL 150-6	AL 150-6		AL 150-6	AL 150-6	AL 150-6
IK MATERIAL/DOME	2219 TAPER →	→	→	→	→	→
IKAGE	2219 ISU →	→	2219 MONO	2219 ISU →	→	→
IDEWALL STRUCTURE	LATCH ONLY	EXP BOLTS	MAN ADJ	LATCH ONLY	MAN ADJ →	→
JLATION	REF →	→	MLI	REF	MLI →	→
IIP THERMAL CONT	H-PIPE PANEL →	→	→	→	→	→
UST STRUCTURE	Ti ISO →	→	FG ISO →	→	→	→
IK SUPPORTS	Ti TUBE →	→	FG TUBE →	→	→	→
ER SYSTEM	BATT	BATT	ADV FCP	BATT	ADV FCP →	→
IDEZVOUS CONCEPT	NONE →	→	LASER	NONE	LASER →	→
DANCE, NAV AND CONTROL	IMU ST →	→	→	→	→	→
A MANAGEMENT	1-CENT 2 RP →	→	2-CENT	1-CENT 2 RP	2-CENT 2 RP →	→

PROGRAMMATIC DATA

OPTION NO.	1	1A	2	3I	3F	3S
DESCRIPTION	INTERIM DIR DEV	INTERIM LOW COST	DELAYED DIR DEV	PHASED INITIAL	PHASED FINAL	PHASED IN PERF
IOC DATE	DEC 79	DEC 79	DEC 83	DEC 79	DEC 83	DEC 83
MULTI-MISSION CAP.	YES →	→	→	→	→	→
PL SPIN UP CAPABILITY	NO →	→	YES	NO	YES →	→
PL POWER PROVISIONS	0	0	300	0	300	300
MISSION DURATION	1 1/2 DAY	1 1/2 DAY	6 DAY	1 1/2 DAY	6 DAY	6 DAY
PAYLOAD DEP (SYNC)	3,521	2,071	7,600	3,531	4,360	8,732
PAYLOAD RET (SYNC)	-	-	4,014	-	2,466	4,136
PAYLOAD RT (SYNC)	983	670	2,063	1,325	1,827	2,636
BURNOUT WEIGHT	7,300	7,566	6,430	7,470	7,100	6,874
GROSS WEIGHT (LESS P/L)	60,336	60,540	63,120	60,335	63,128	63,105
USABLE PROPELLANT	51,302	51,302	56,332	51,212	54,861	55,827
MASS FRACTION	0.865	0.862	0.888	0.863	0.885	0.872
DDT&E $ MILLIONS	187.85	177.01	288.77	188.1	88.8	
OPERATIONS $ MILLIONS	288.81	-	188.46	88.8	284.5	
PRODUCTION $ MILLIONS	178.57	-	214.38	82.8	178.8	
TOTAL PROGRAM $ MILLIONS	677.43	-	682.90	377.3	478.1	
FLEET SIZE	13	-	12	5	11	10
PEAK FUNDING/YR $ MILLIONS	78.7/78	-	124/82	78.7/78	88.2/81	
MAIN STAGE (1ST UNIT) $ MILLIONS	14.04	-	18.08	16.03	17.4	
MAIN STAGE (AVG) $ MILLIONS	12.82	-	16.01	14.7	15.80	
KICK STAGE $ MILLIONS	2.30	-	3.47	0.76	0.91	

Section 2
CONFIGURATION DEFINITION

2.1 INBOARD PROFILE DRAWING

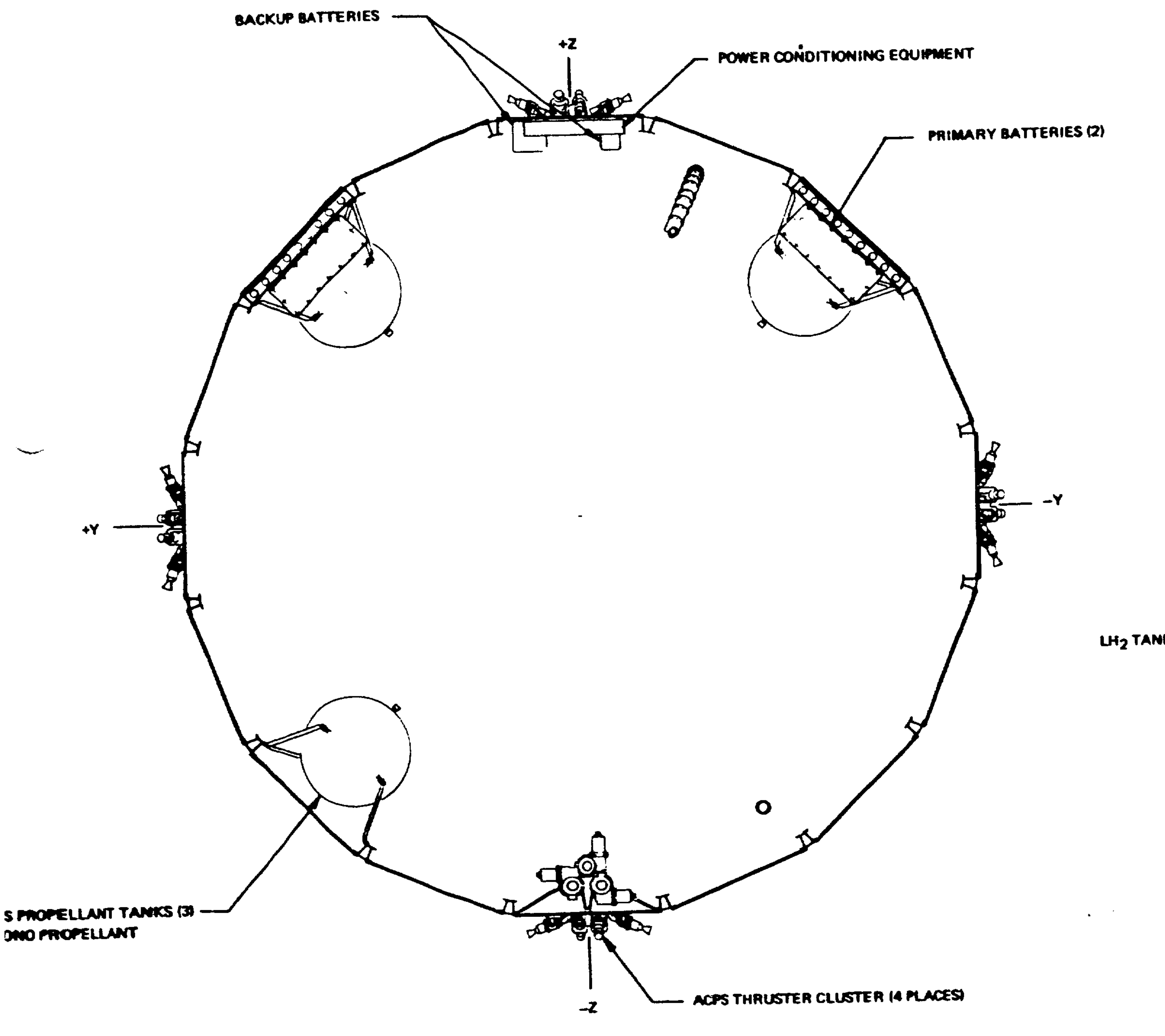
The Cryogenic Tug Option 3I will contain 51,212 lb of usable LH_2 and LO_2 propellants (mixture ratio = 5.5) for operation of its Category I RL10 main engine. The configuration (Figure 2-1) consists of primary structure, thermal control provisions, avionics and propulsion subsystem, and Shuttle interface accommodations. The vehicle has an overall diameter of 176 inches (14.7 ft) and a total length of 389.8 inches (32.5 ft). The stage dry weight and gross weight less payload are 6,606 lb and 59,335 lb, respectively.

The Cryogenic Tug Option 3F will be essentially identical to Option 3I in basic configuration appearance. In the nominal mission it will be loaded with 54,661 lb of usable LH_2 and LO_2 propellants at a mixture ratio of 5.5. The basic configuration equipment are identified in Figure 2-2. Dimensions of the vehicle are identical to Option 3I, while the dry weight and gross weight less payload change to 6,254 lb and 63,120 lb, respectively.

2.2 STRUCTURES SUBSYSTEM SUMMARY (WBS 320-03-01)

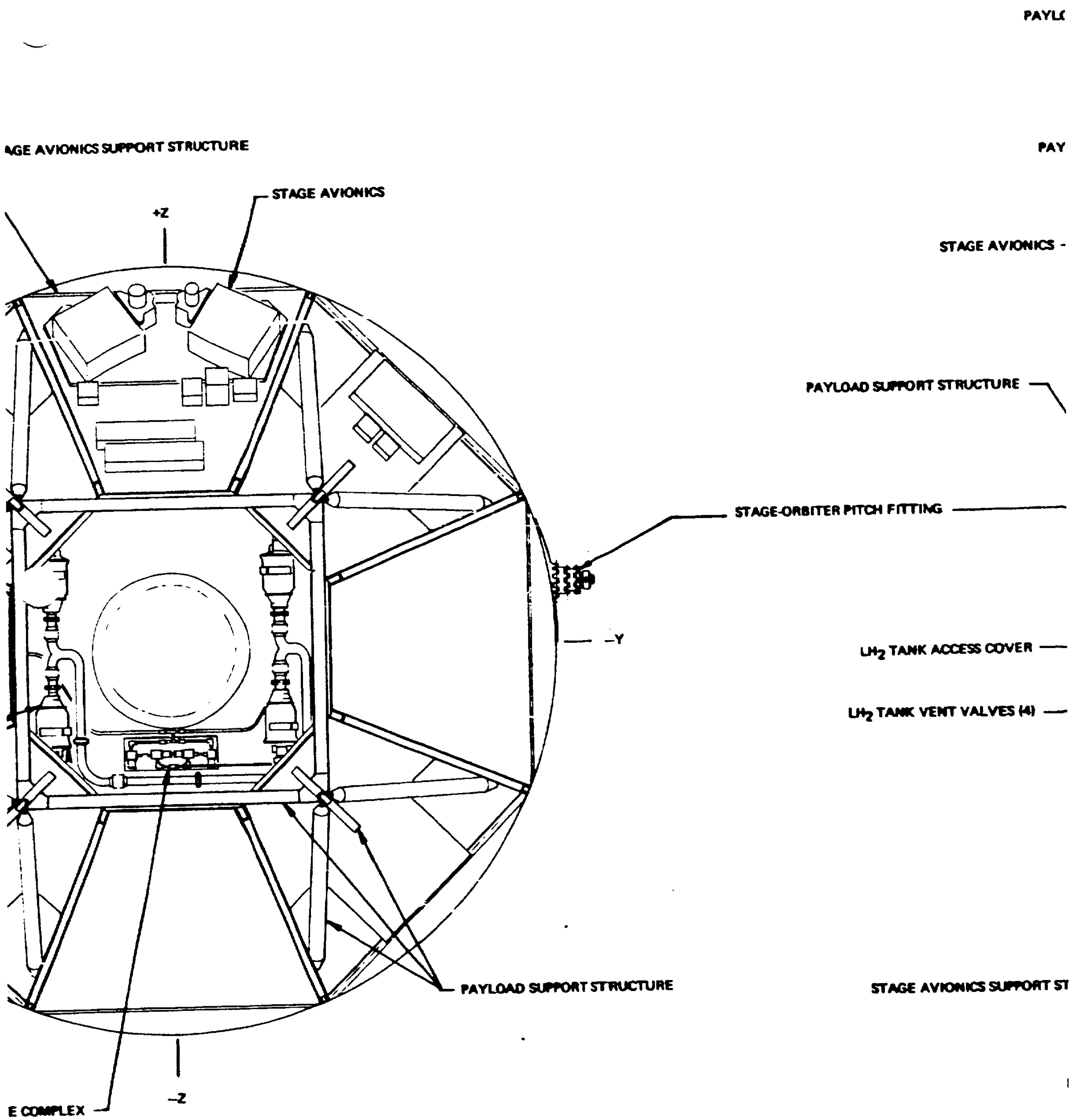
The structural concept is designed to meet the program requirements established for Option 3I and 3F as described in Section 1.

For this vehicle, the structural arrangement and structural element details are similar to Option 1. Primary differences are in the tank support and thrust structure materials to attain the option goal of low DDT&E costs but phasable to longer mission duration. Figure 2-3 identifies the configuration and primary structural subsystems. Table 2-1 provides the structural materials used.

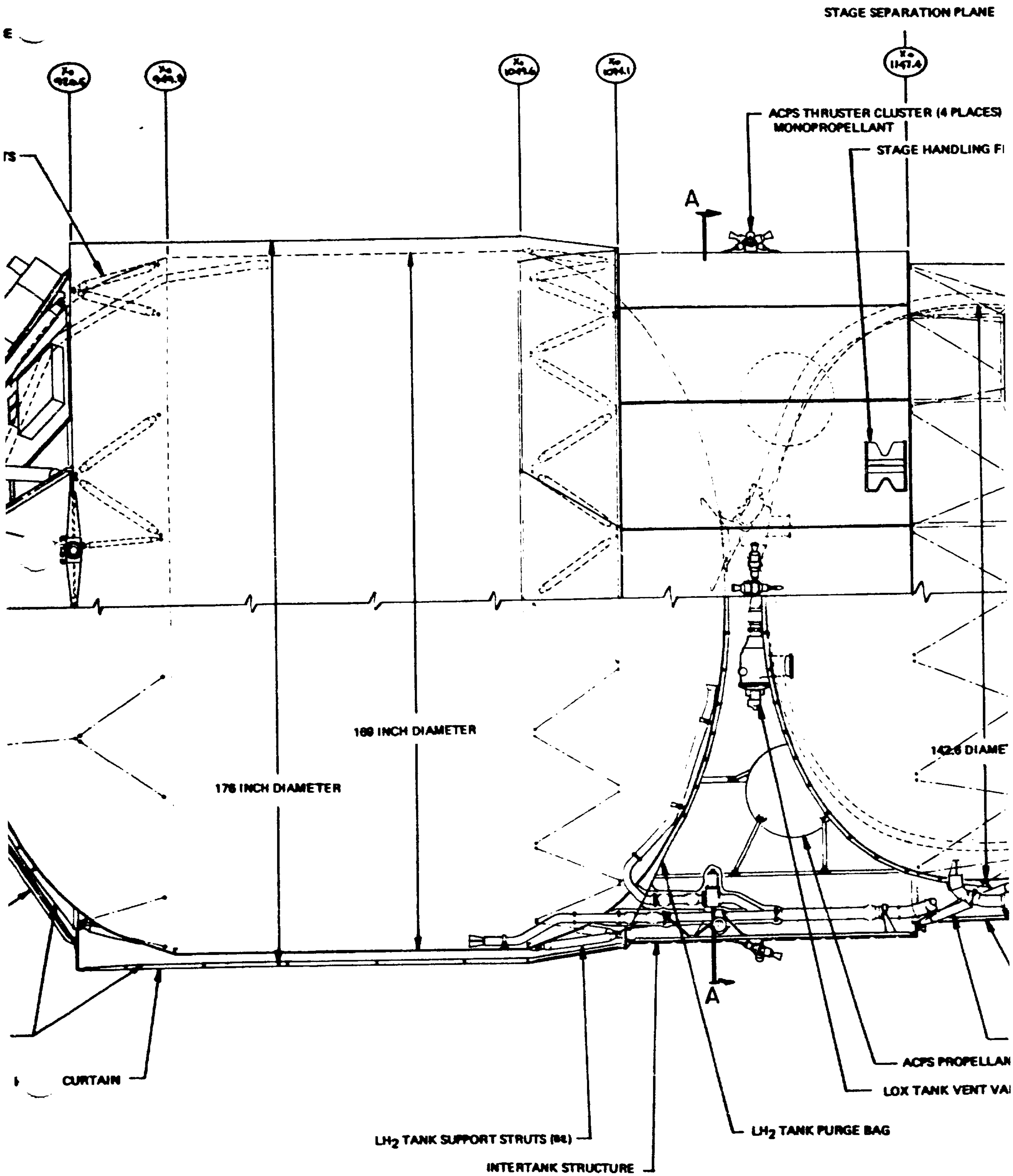


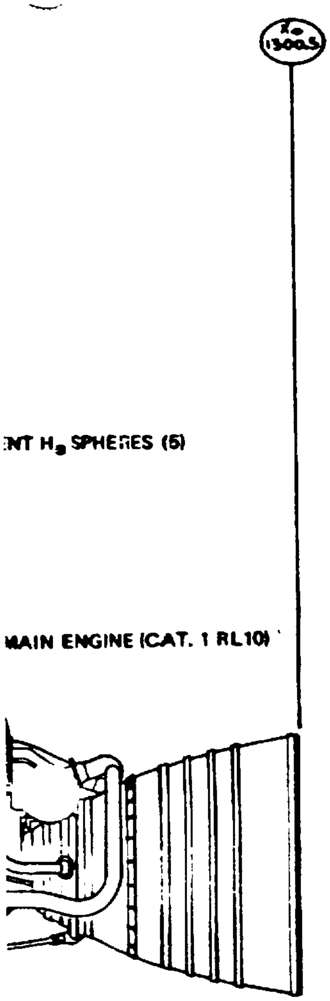
BACKUP BATTERIES
+Z
POWER CONDITIONING EQUIPMENT
PRIMARY BATTERIES (2)
+Y
-Y
LH2 TANK
S PROPELLANT TANKS (3)
ONO PROPELLANT
-Z
ACPS THRUSTER CLUSTER (4 PLACES)

SECTION A-A

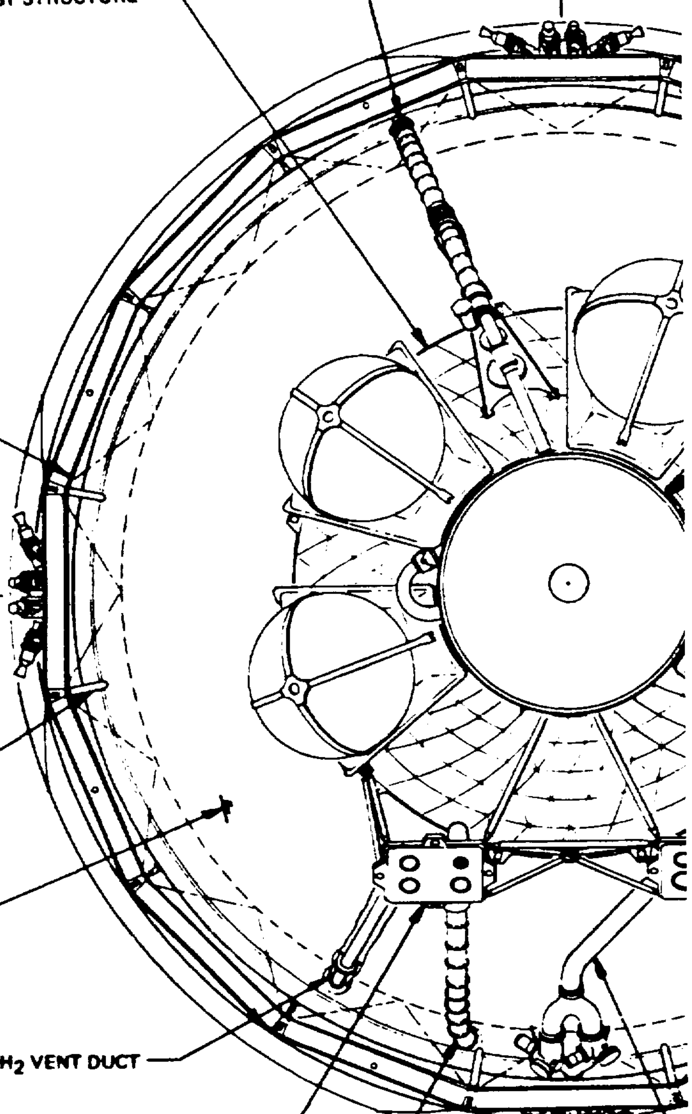


PAYL(
AGE AVIONICS SUPPORT STRUCTURE
PAY
STAGE AVIONICS
+Z
STAGE AVIONICS -
PAYLOAD SUPPORT STRUCTURE
STAGE-ORBITER PITCH FITTING
-Y
LH2 TANK ACCESS COVER
LH2 TANK VENT VALVES (4)
PAYLOAD SUPPORT STRUCTURE
STAGE AVIONICS SUPPORT ST
-Z
E COMPLEX

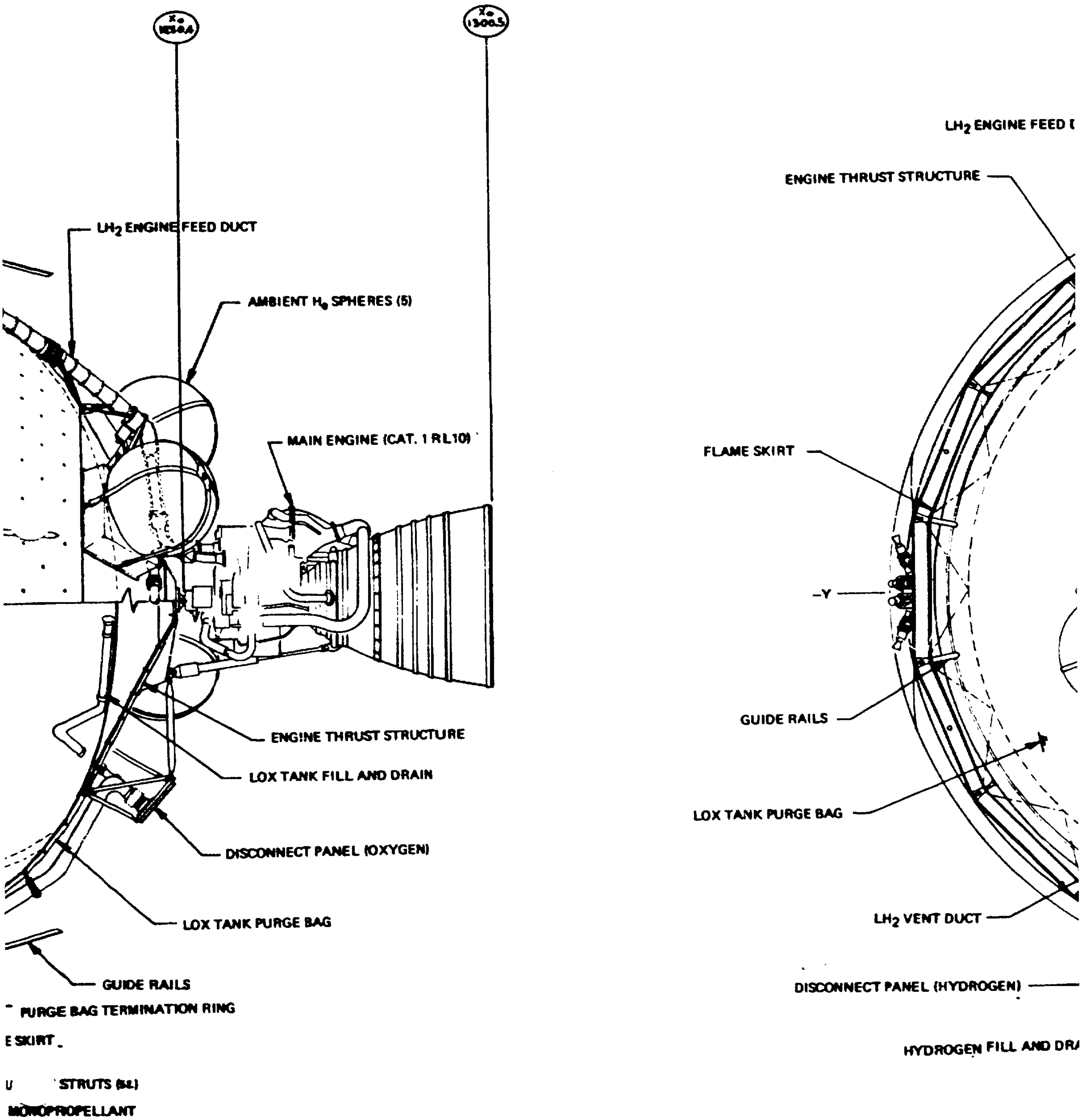

STAGE SEPARATION PLANE
Xo 1147.4
ACPS THRUSTER CLUSTER (4 PLACES)
MONOPROPELLANT
STAGE HANDLING FI
A
168 INCH DIAMETER
176 INCH DIAMETER
142.6 DIAMET
A
CURTAIN
ACPS PROPELLAN
LOX TANK VENT VA
LH2 TANK PURGE BAG
LH2 TANK SUPPORT STRUTS (84)
INTERTANK STRUCTURE



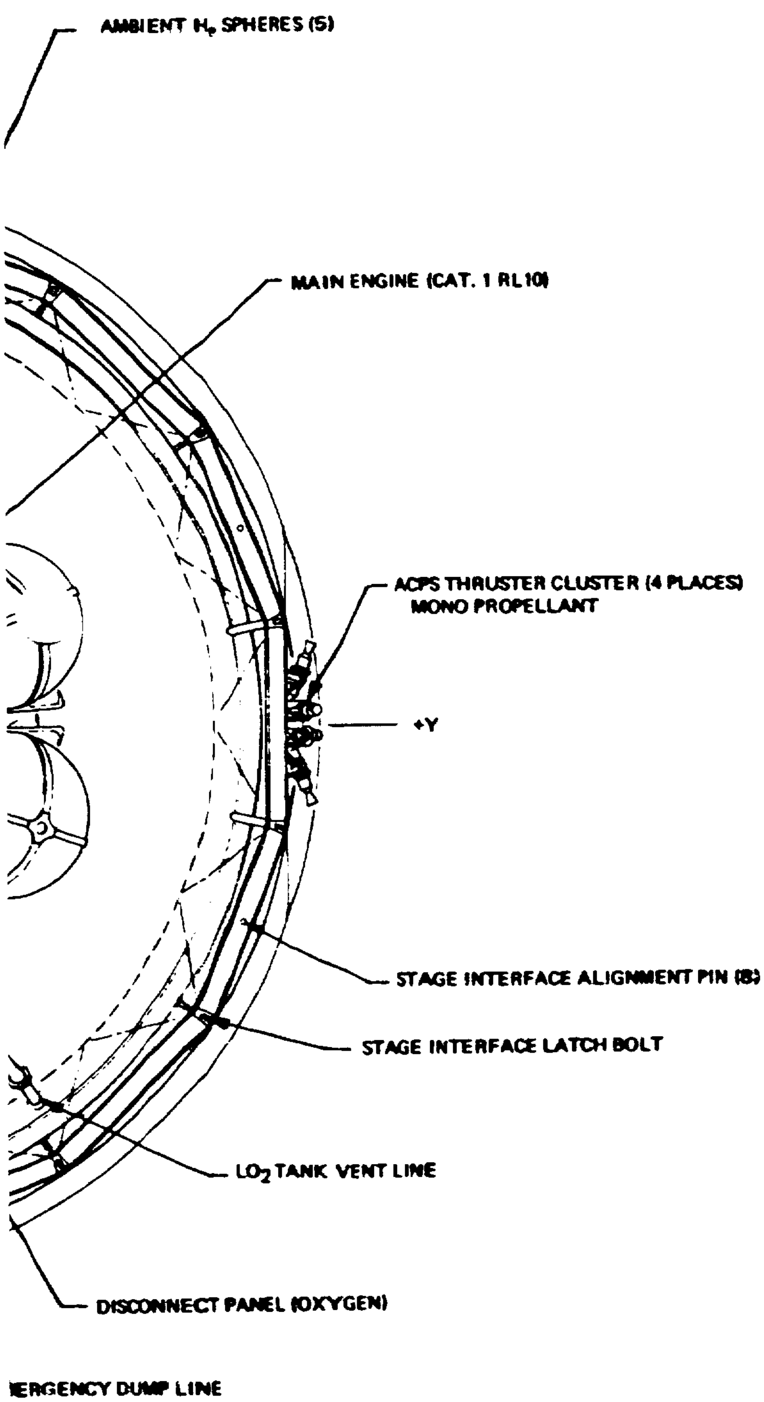
Xo 1300.5
NT H2 SPHERES (5)
MAIN ENGINE (CAT. 1 RL10)
GINE THRUST STRUCTURE
ANK FILL AND DRAIN
CT PANEL (OXYGEN)
E BAG



LH2 ENGINE FEED DUCT
+Z
ENGINE THRUST STRUCTURE
FLAME SKIRT
–Y
GUIDE RAILS
LOX TANK PURGE BAG
LH2 VENT DUCT
DISCONNECT PANEL (HYDROGEN)
HYDROGEN FILL AND DRAIN
–Z

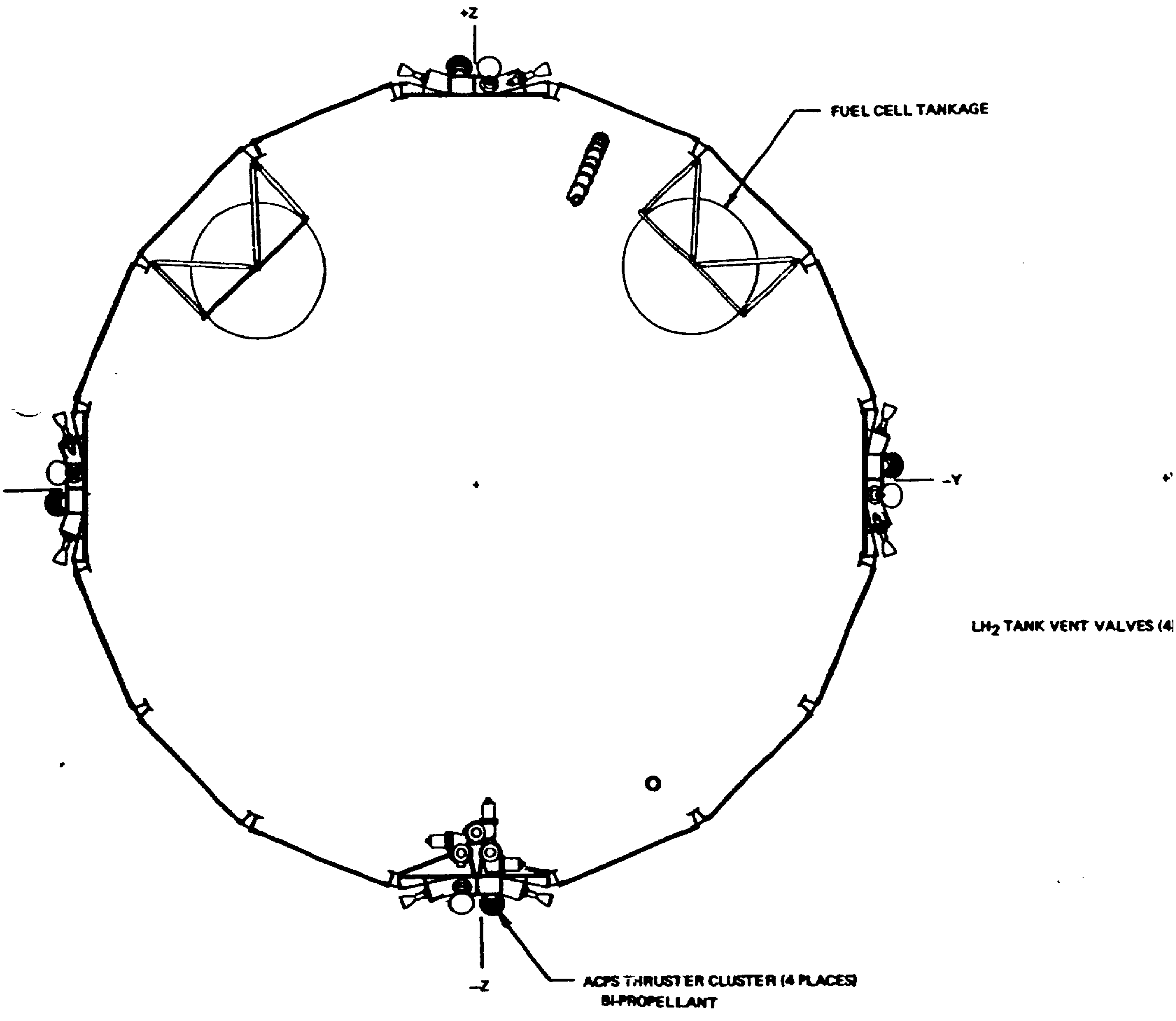


LH2 ENGINE FEED DUCT
AMBIENT He SPHERES (5)
MAIN ENGINE (CAT. 1 RL10)
ENGINE THRUST STRUCTURE
LOX TANK FILL AND DRAIN
DISCONNECT PANEL (OXYGEN)
LOX TANK PURGE BAG
GUIDE RAILS
PURGE BAG TERMINATION RING
E SKIRT
STRUTS
MONOPROPELLANT
ENGINE THRUST STRUCTURE
FLAME SKIRT
-Y
GUIDE RAILS
LOX TANK PURGE BAG
LH2 VENT DUCT
DISCONNECT PANEL (HYDROGEN)

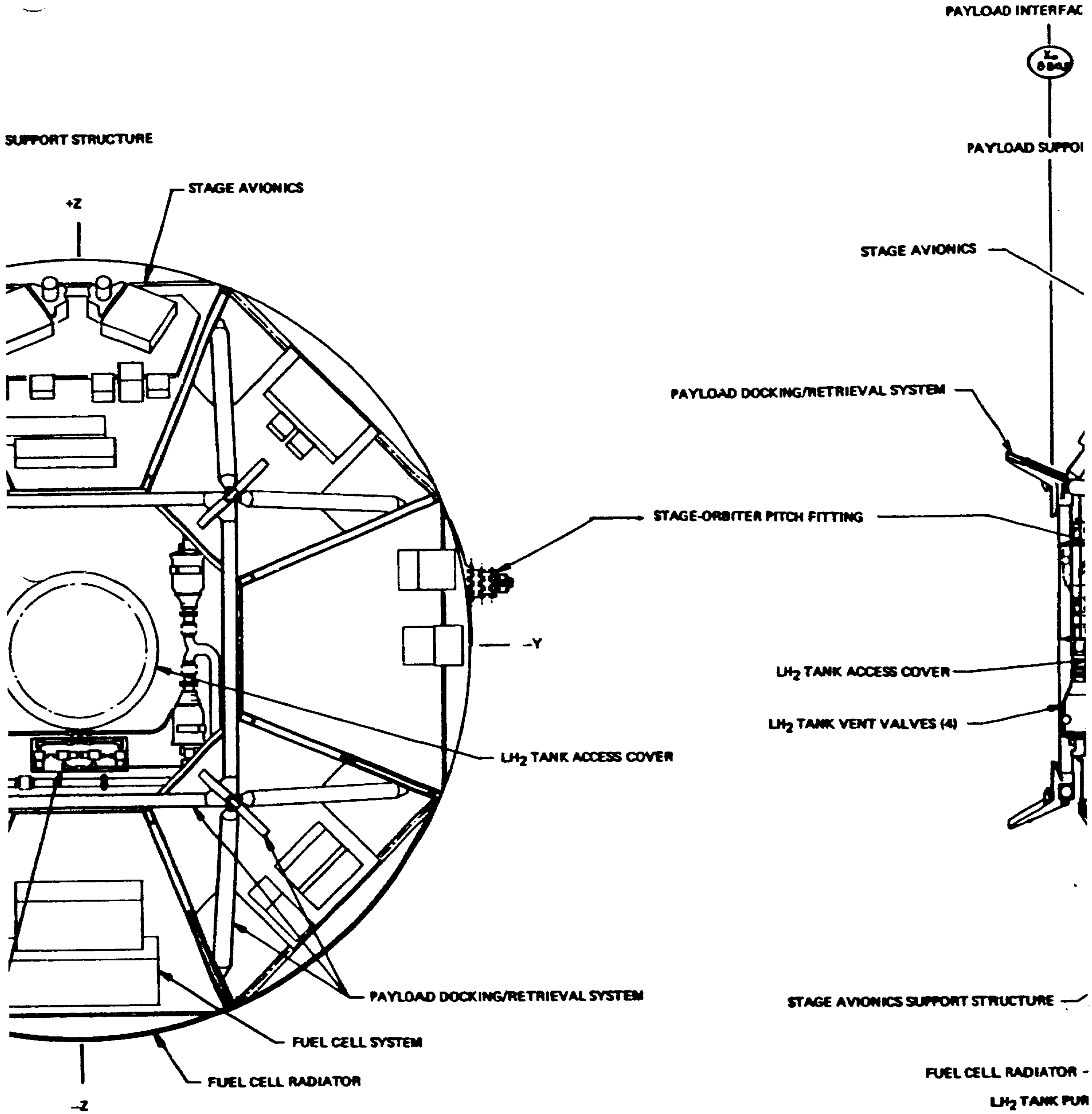


AMBIENT H_e SPHERES (5)
MAIN ENGINE (CAT. 1 RL10)
ACPS THRUSTER CLUSTER (4 PLACES) MONO PROPELLANT
+Y
STAGE INTERFACE ALIGNMENT PIN (8)
STAGE INTERFACE LATCH BOLT
LO_2 TANK VENT LINE
DISCONNECT PANEL (OXYGEN)
ERGENCY DUMP LINE

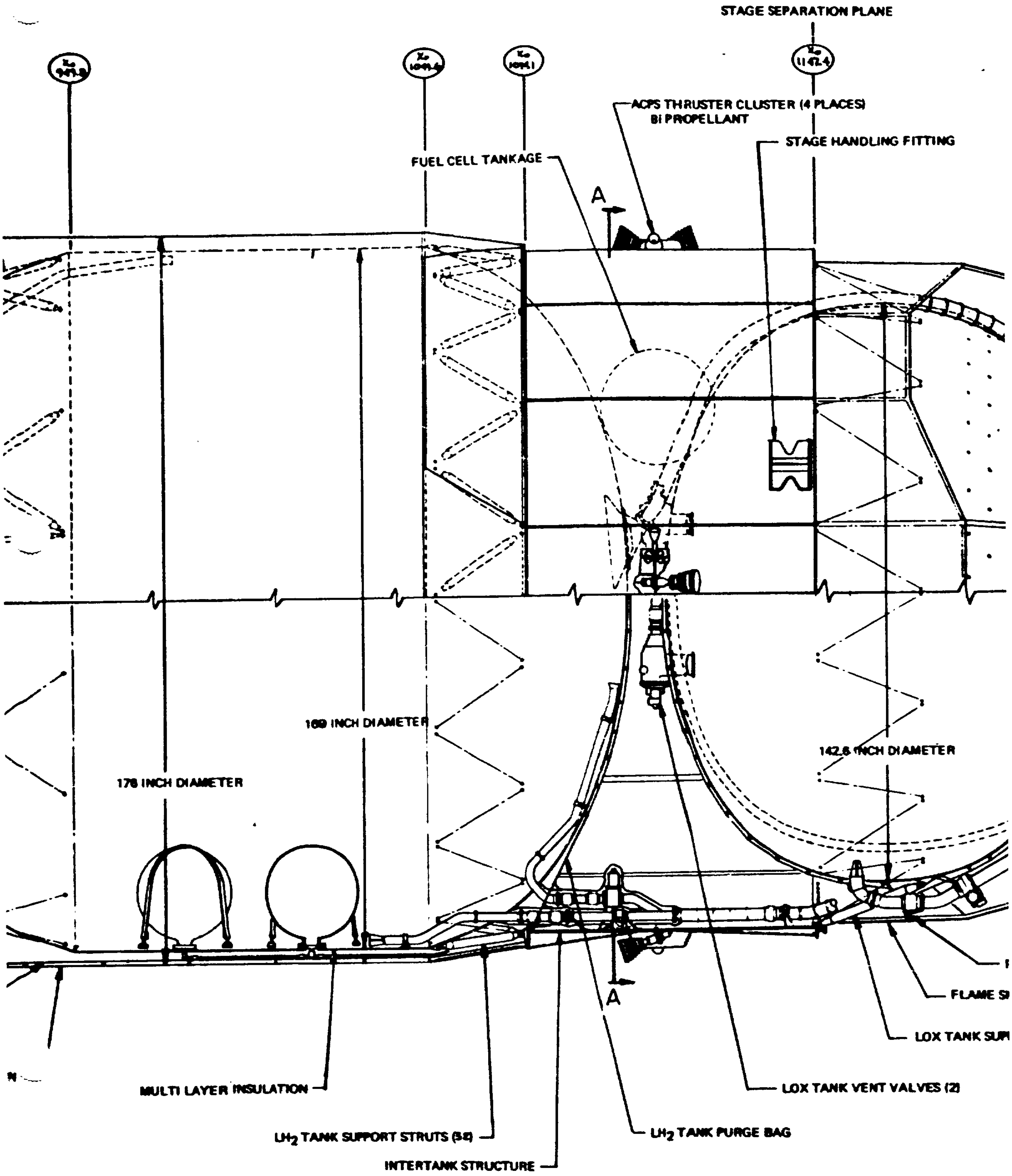
Figure 2-1.

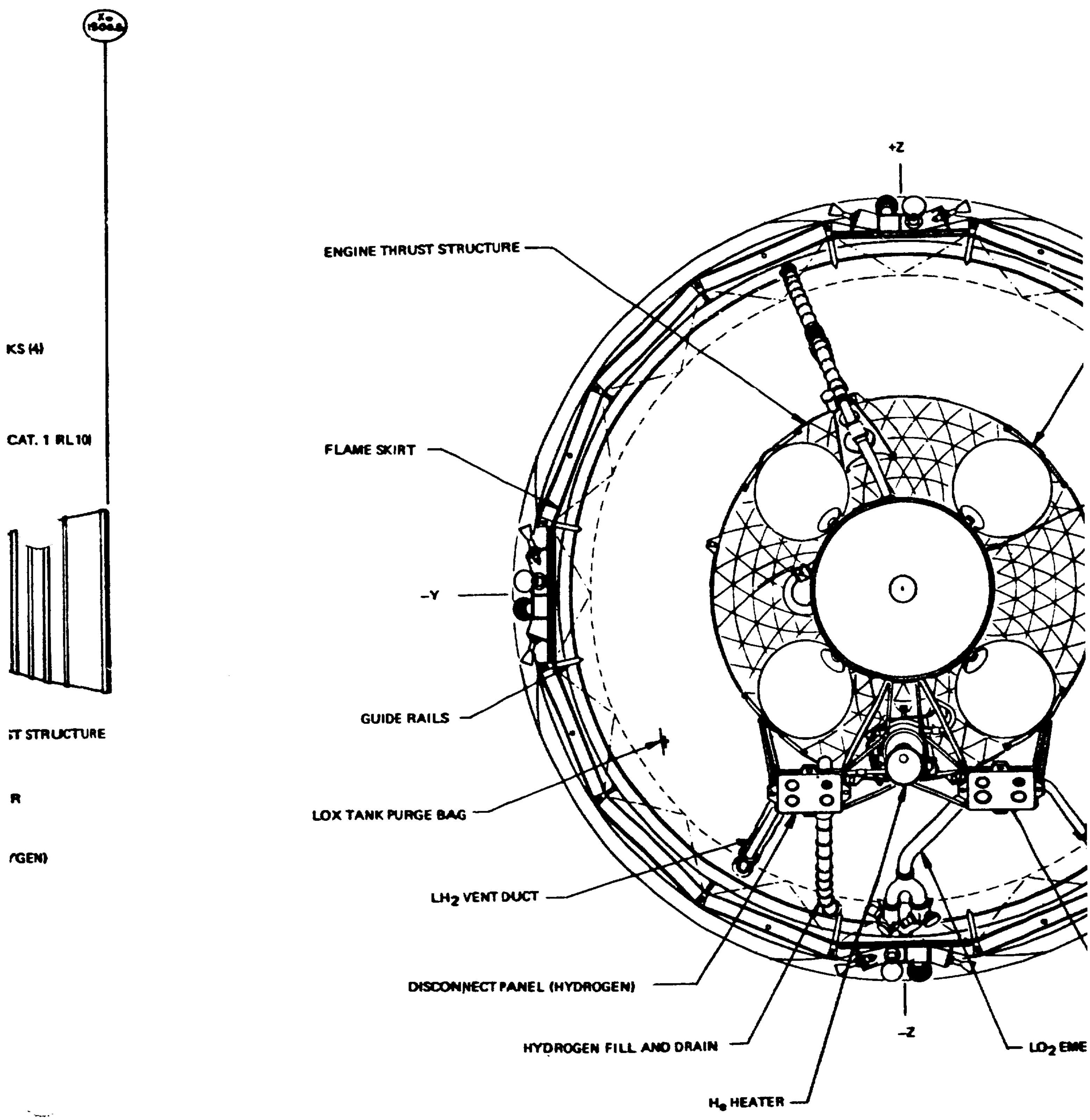

+Z
FUEL CELL TANKAGE
-Y
LH2 TANK VENT VALVES (4)
-Z
ACPS THRUSTER CLUSTER (4 PLACES)
BI-PROPELLANT

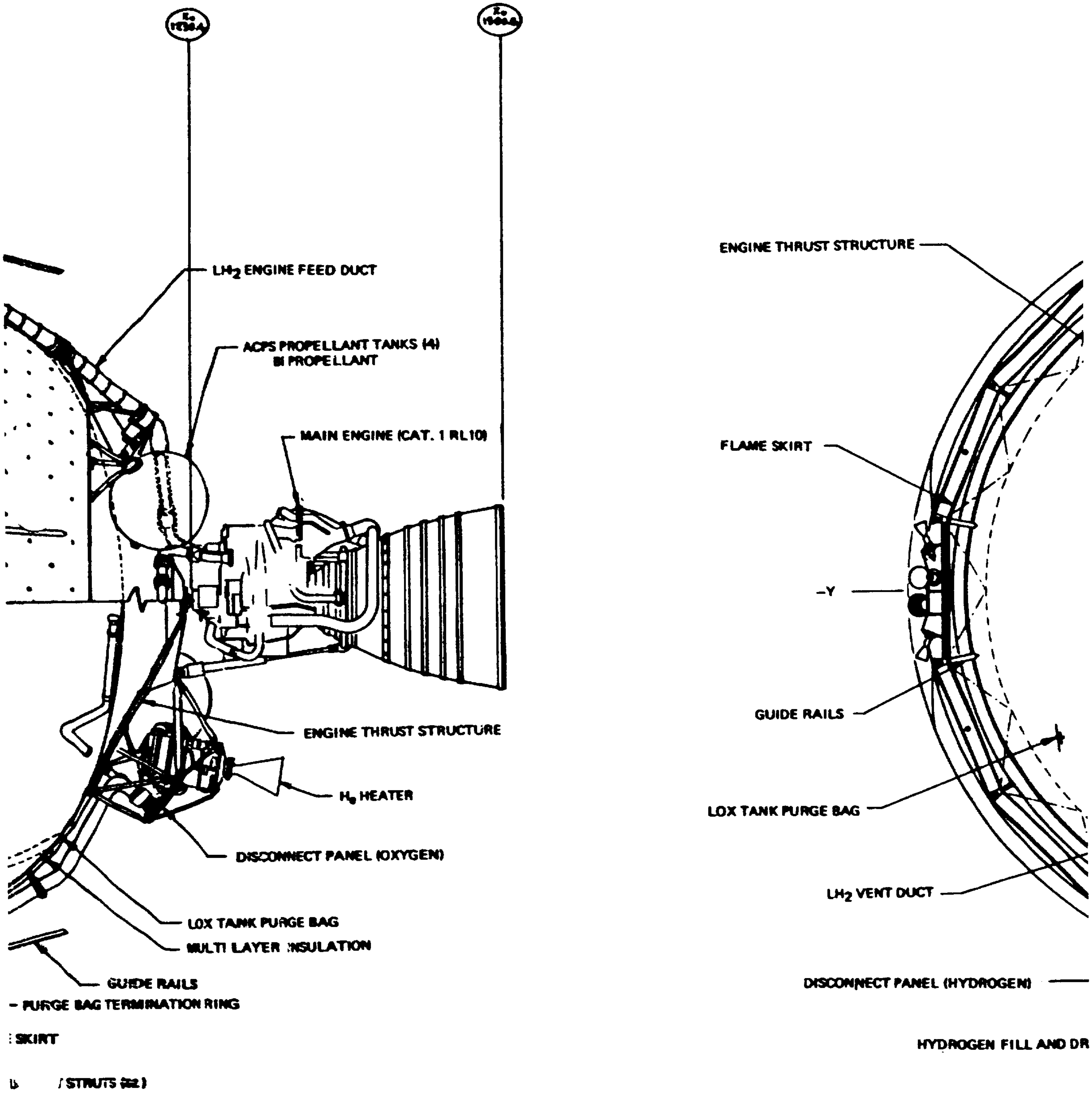
SECTION A-A



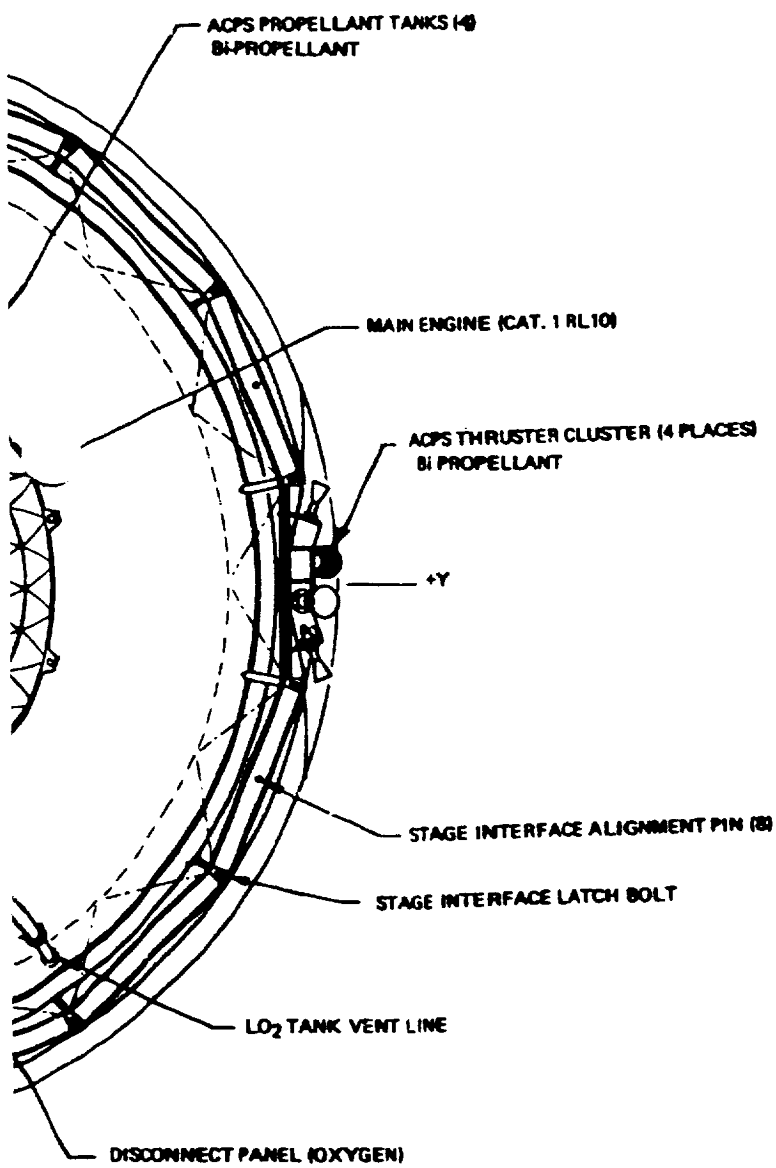
SUPPORT STRUCTURE
STAGE AVIONICS
+Z
STAGE-ORBITER PITCH FITTING
-Y
LH_2 TANK ACCESS COVER
PAYLOAD DOCKING/RETRIEVAL SYSTEM
FUEL CELL SYSTEM
FUEL CELL RADIATOR
-Z
PAYLOAD INTERFAC
PAYLOAD SUPPOI
STAGE AVIONICS
PAYLOAD DOCKING/RETRIEVAL SYSTEM
STAGE-ORBITER PITCH FITTING
LH_2 TANK ACCESS COVER
LH_2 TANK VENT VALVES (4)
STAGE AVIONICS SUPPORT STRUCTURE
FUEL CELL RADIATOR
LH_2 TANK PUI


STAGE SEPARATION PLANE
ACPS THRUSTER CLUSTER (4 PLACES)
BI PROPELLANT
STAGE HANDLING FITTING
FUEL CELL TANKAGE
A
A
169 INCH DIAMETER
178 INCH DIAMETER
142.6 INCH DIAMETER
MULTI LAYER INSULATION
LH2 TANK SUPPORT STRUTS (58)
INTERTANK STRUCTURE
LH2 TANK PURGE BAG
LOX TANK VENT VALVES (2)


KS (4)
CAT. 1 RL10)
T STRUCTURE
R
(GEN)
+Z
ENGINE THRUST STRUCTURE
FLAME SKIRT
-Y
GUIDE RAILS
LOX TANK PURGE BAG
LH_2 VENT DUCT
DISCONNECT PANEL (HYDROGEN)
-Z
HYDROGEN FILL AND DRAIN
H_e HEATER
LO_2 EME



LH2 ENGINE FEED DUCT
ACPS PROPELLANT TANKS (4)
BI PROPELLANT
MAIN ENGINE (CAT. 1 RL10)
ENGINE THRUST STRUCTURE
HEATER
DISCONNECT PANEL (OXYGEN)
LOX TANK PURGE BAG
MULTI LAYER INSULATION
GUIDE RAILS
PURGE BAG TERMINATION RING
SKIRT
STRUTS
ENGINE THRUST STRUCTURE
FLAME SKIRT
-Y
GUIDE RAILS
LOX TANK PURGE BAG
LH2 VENT DUCT
DISCONNECT PANEL (HYDROGEN)
HYDROGEN FILL AND DR



ENCY DUMP LINE

Figure 2-2.

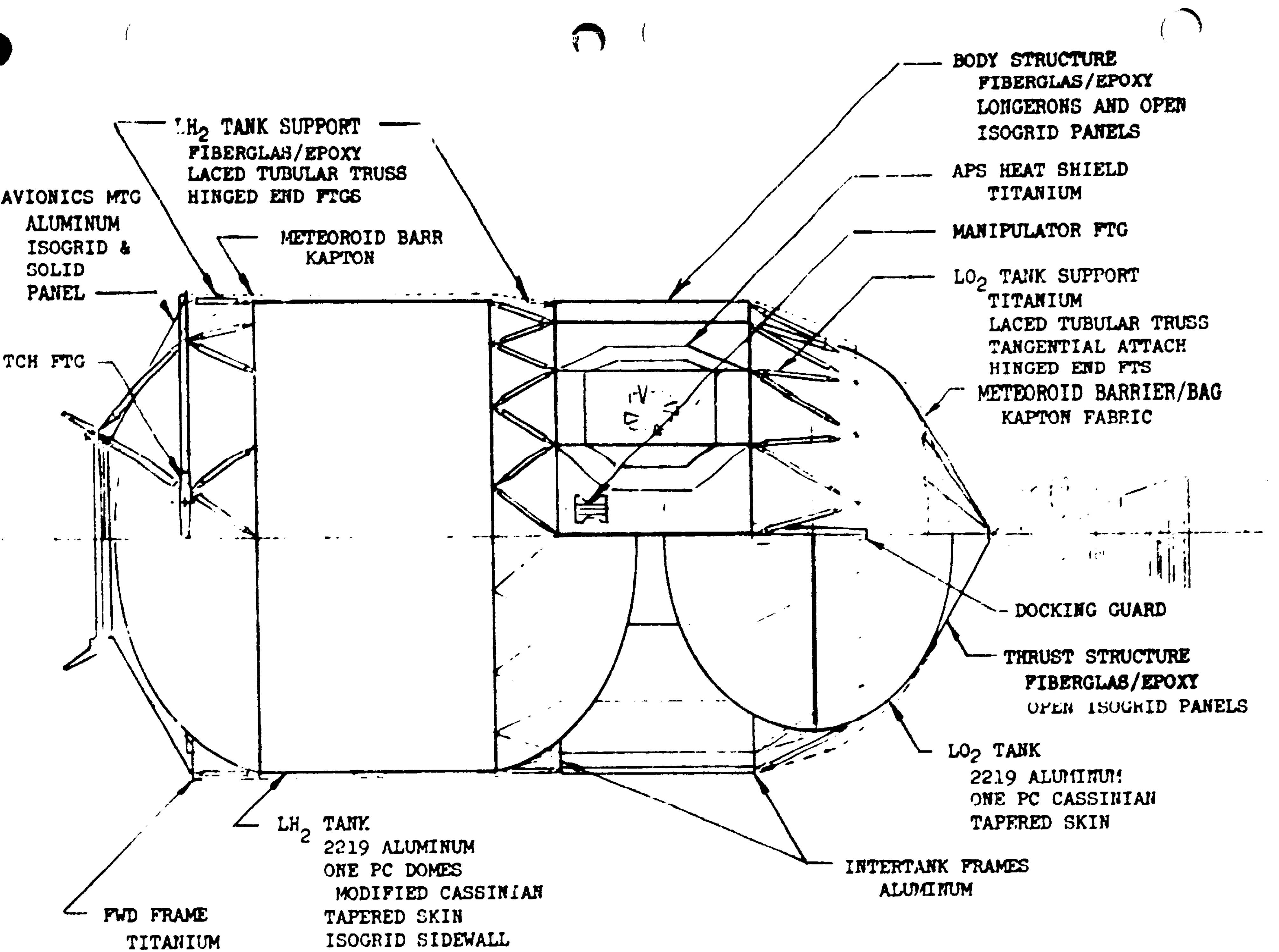

LH2 TANK SUPPORT
FIBERGLAS/EPOXY
LACED TUBULAR TRUSS
HINGED END FTGS
AVIONICS MTG
ALUMINUM
ISOGRID &
SOLID
PANEL
METEOROID BARR
KAPTON
TCH FTG
BODY STRUCTURE
FIBERGLAS/EPOXY
LONGERONS AND OPEN
ISOGRID PANELS
APS HEAT SHIELD
TITANIUM
MANIPULATOR FTG
LO2 TANK SUPPORT
TITANIUM
LACED TUBULAR TRUSS
TANGENTIAL ATTACH
HINGED END FTS
METEOROID BARRIER/BAG
KAPTON FABRIC
DOCKING GUARD
THRUST STRUCTURE
FIBERGLAS/EPOXY
OPEN ISOGRID PANELS
LO2 TANK
2219 ALUMINUM
ONE PC CASSINIAN
TAPERED SKIN
LH2 TANK
2219 ALUMINUM
ONE PC DOMES
MODIFIED CASSINIAN
TAPERED SKIN
ISOGRID SIDEWALL
INTERTANK FRAMES
ALUMINUM
FWD FRAME
TITANIUM

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Table 2-1

STRUCTURAL MATERIALS

Arrangement:	Load carrying tank (LCT)
LH_2 Tank:	2219 Al-isogrid cylinder - 1 pc tapered modified cass dome
LO_2 Tank:	2219 Al - 1 pc tapered cassinian domes
Tank Supports:	Hinged F.G./epoxy tubes
	Attached at LH_2 dome/cyl joint
	Tangentially attached to LO_2 dome
Body structure-load carrying tank/supports forward	
	7075 alum longerons/open isogrid panels mid-tank
Thrust Structure:	Open isogrid fiberglass epoxy
Meteoroid Barrier:	Fabric bag

The load carrying tank (LCT) arrangement incorporates an isogrid-stiffened 2219 aluminum fuel tank sidewall and tubular truss tank supports as primary structure between the payload support frame and the constant section inter-tank shell. Eight FG/epoxy trusses attach to the forward end of the tank cylinder at sixteen equally spaced points. The trusses tie to the forward support frame at eight hard points where the payload support trusses and the avionics support panel joints also attach providing good load path continuity. This forward titanium frame also reacts the stage support pitch loads with a pivoted fitting on the side of the stage. The avionics mounting panel is an aluminum isogrid with integrally machined heat sink panels for component mounting/heat conduction to the attached heat pipes.

At the aft end of the fuel tank cylinder, 16 laced tubular trusses carry the body structure loads from 32 points on the tank to 16 longeron locations on the intertank shell at a field joint frame. These square tube section aluminum longerons carry the concentrated axial/bending loads to the stage support separation plane at the aft end of the shell. Longeron stability and torsional/bending shear capability are provided by open aluminum isogrid panels. These panels are attached to the longerons and to the aluminum frames at the forward field joint and the aft separation plane. The panels are all shear carrying and are alternately fixed and hinged for component mounting and access. All panels are flat for manufacturing and mounting simplicity.

The oxidizer tank is supported by laced tubular trusses which attach tangentially to pads on the tank below the tank equatorial plane, and to the stage separation plane frame. Fuel tank supports attach to the tank cylinder/dome intersection where the tank dome shape transitions to a local conic to provide attachment clearance. All supports are hinged to eliminate radial con-straint on the tank. The tank cylinder is extended approximately 12 1/2 inche at each end from a theoretical tangential joint location to intersect with the 70-degree-half-angle dome conic.

Domes of both tanks are fabricated in one piece of tapered 2219 aluminum. Meridonal weldments are not required and only single circumferential welds are used at the dome joints. No ring inserts are required. Doors are provided at

the forward end of the LH_2 tank and Tug aft end of the LO_2 tank domes f
internal stores/lines access.

Engine thrust is carried into the aft dome of the LO_2 tank by an open i
thrust structure. This structure is assembled from 12 similar flat pan
joined at their edges. Local cut outs in the panels are provided for line routings. Attachment to the tank is provided at the 12 corner join flat panels incorporate nodal point attachment provisions at the isogri triangle intersections. This provides standard mounting locations for c attachment.

For the short mission duration, meteoroid protection is provided by a 6 fabric cover over the sidewall of the fuel tank and across the end dome tanks. This material also serves as the reflective insulation system pu The barrier provides in excess of 0.995 probability of no unacceptable damage. Table 2-1 summarizes the several structural element definition

As this vehicle is phased from the initial to the final configuration, structural elements remain unchanged. To accommodate the longer missio tion and meteoroid exposure, greater protection is required. This prot is provided by the additional thermal insulation that is also required form the longer mission. This insulation change is discussed in Sectio The payload interface structural/mechanical system also changes in this capability as described in Section 2.7.

Structural analysis and trade studies are discussed in detail in Volume

2.3 THERMAL CONTROL SUBSYSTEM SUMMARY (WBS 320-03-02)

The thermal control system is designed to meet the program requirements established for Option 3I and 3F as discussed in Section 1.

The thermal control of the fuel tank on the 3I option is accomplished w radiation barrier consisting of a low emissivity surface (vapor deposit aluminum) on the inside of the bag which envelops the tank, and a highl reflective sheet of double aluminized mylar (DAM) on the tank. Cylindr of a Dacron net separate the DAM reflector from the tank surface to reduce convection heat transfer and the potential for liquefying nitrogen on the exterior surface of the bag during ground hold. The thermal control of the oxidizer tank is accomplished with a system identical to that for the fuel tar except the layers of Dacron net are not needed on the oxidizer tank. (See Figure 2-4.)

The thermal control of the fuel and oxidizer tanks on the 3F option is accomplished with a multilayer insulation (MLI) system. Alternate layers of double aluminized mylar (DAM) and a Dacron net were selected for the MLI. The layers are held together in an integral panel with fasteners which have a small diameter shank. The outer layers of the MLI panels are face sheets which protect the panel and which carry the structural loads. The panels are joined at their edges by lacing and Velcro.

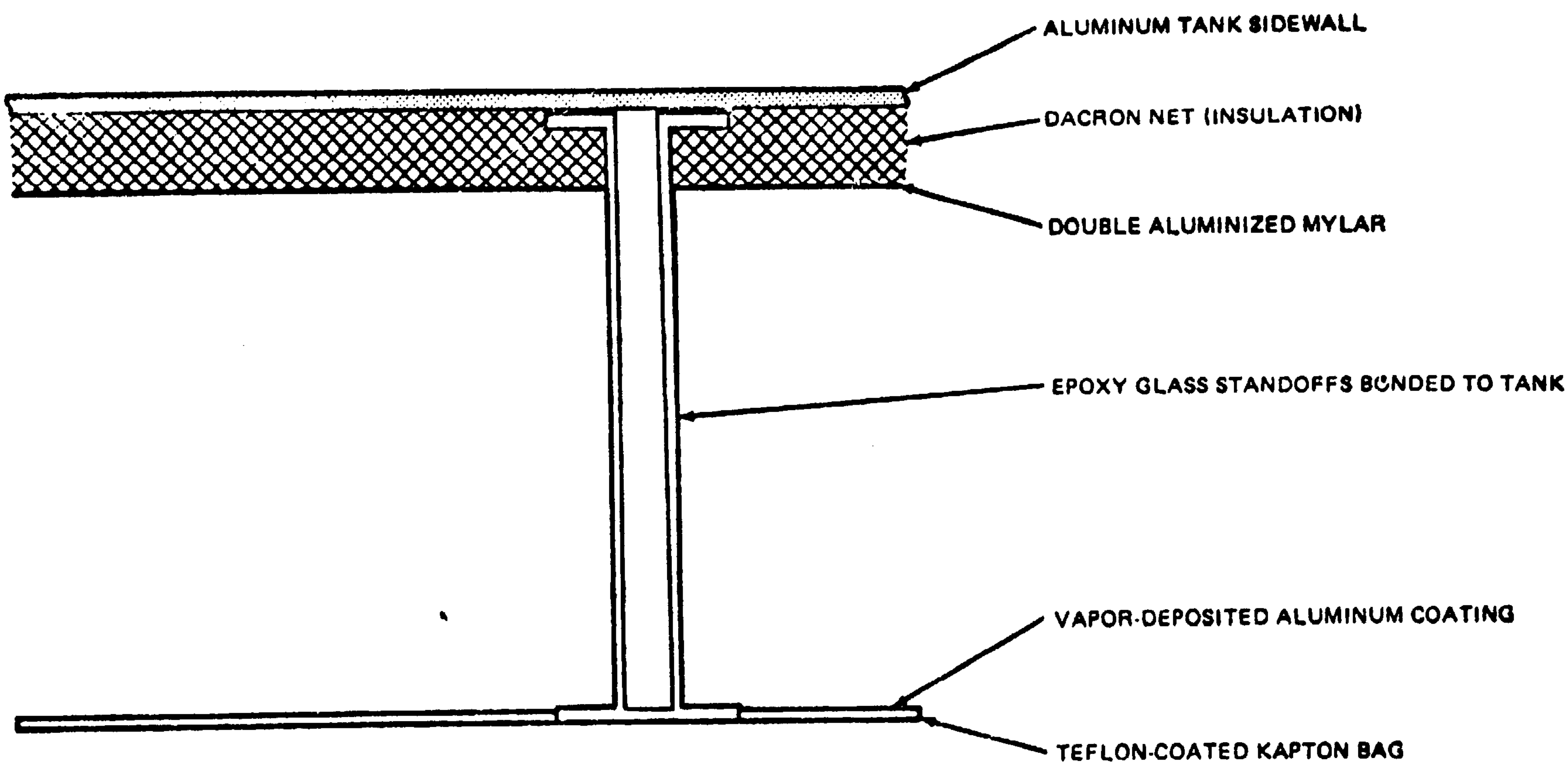
Separate bags envelop each of the tanks. These bags ensure the presence of gases which will not liquefy or freeze on the tank exterior and within the insulation system during ground hold, ascent, and reentry. Helium is used for both the pre-flight purging and the reentry repressurization of the bag. Large valves in the bags and bag standoffs are used to allow a rapid evacuation of the purge gas during ascent. Pressure controllers are used to control the repressurization of the bags during reentry. Standoffs between the tank and MLI as well as the standoffs between the MLI and the bag facilitate purging the option 3F insulation system (Figure 2-5).

A schematic of the purge system is shown in Figure 2-6. This schematic is applicable to both 3I and 3F.

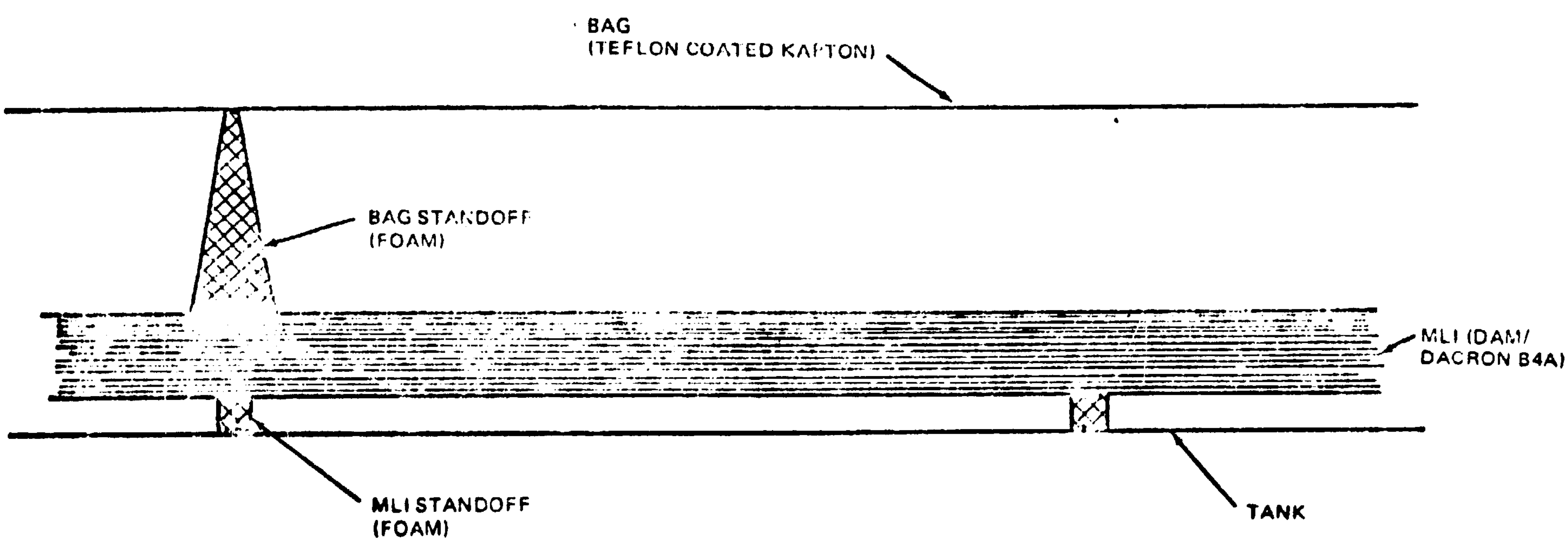
Thermal analysis and trade studies are discussed in detail in Volume 5.

2.4 AVIONICS SUBSYSTEM SUMMARY (WBS 320-03-03)

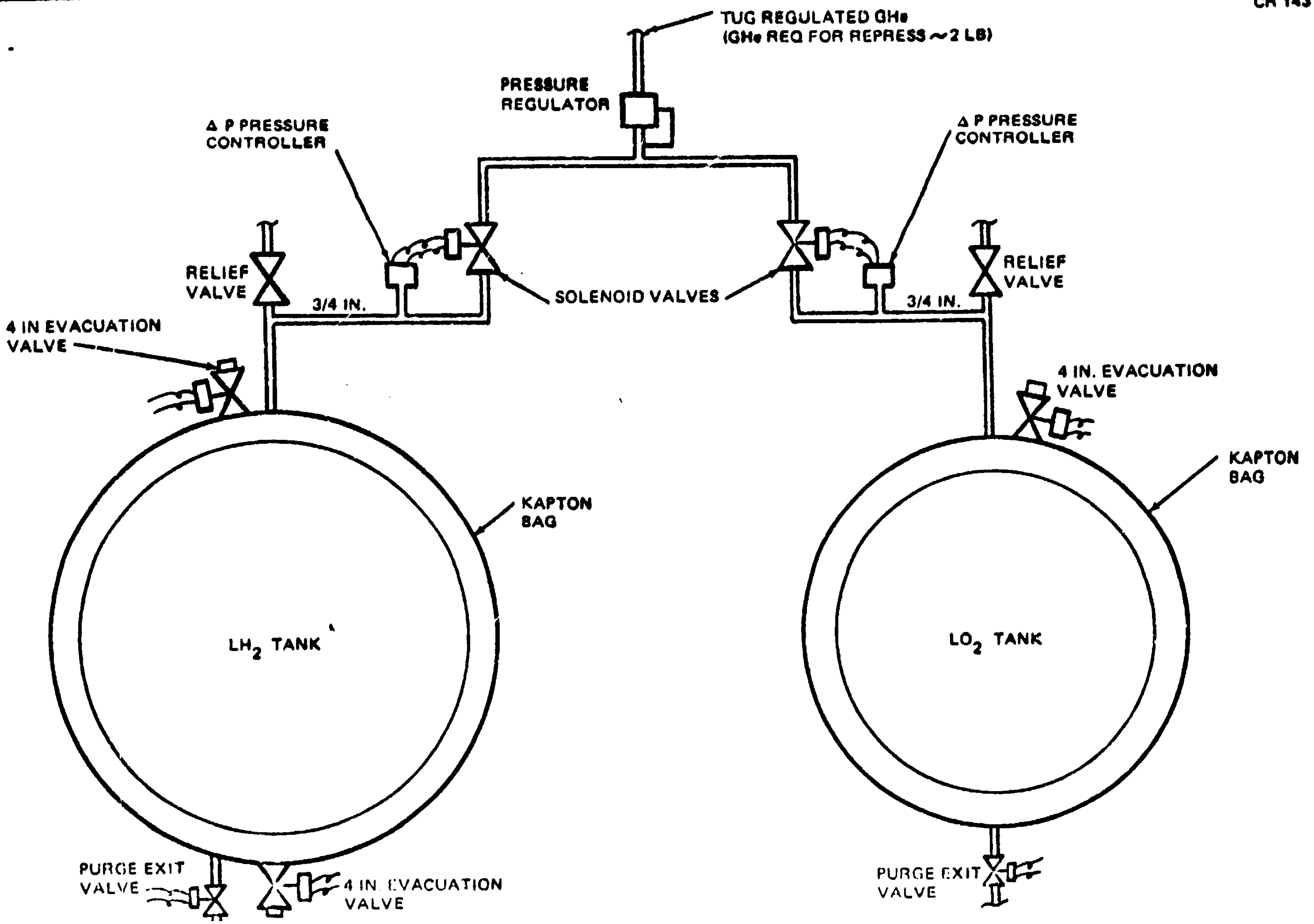
Program Option 3 is a phased developed program. The objectives of vehicle 3I are to minimize the initial DDT&E costs. In addition the mission duration is 36 hours and the vehicle must operate under Autonomy Level IV. The initial design has compromised weight/reliability in order to achieve these goals.


ALUMINUM TANK SIDEWALL
DACRON NET (INSULATION)
DOUBLE ALUMINIZED MYLAR
EPOXY GLASS STANDOFFS BONDED TO TANK
VAPOR-DEPOSITED ALUMINUM COATING
TEFLON-COATED KAPTON BAG

CR143



BAG
(TEFLON COATED KAPTON)
BAG STANDOFF
(FOAM)
MLI (DAM/
DACRON B4A)
MLI STANDOFF
(FOAM)
TANK


TUG REGULATED GHe
(GHe REQ FOR REPRESS ~2 LB)
PRESSURE
REGULATOR
Δ P PRESSURE
CONTROLLER
Δ P PRESSURE
CONTROLLER
RELIEF
VALVE
RELIEF
VALVE
3/4 IN.
3/4 IN.
SOLENOID VALVES
4 IN EVACUATION
VALVE
4 IN. EVACUATION
VALVE
KAPTON
BAG
KAPTON
BAG
LH2 TANK
LO2 TANK
PURGE EXIT
VALVE
4 IN. EVACUATION
VALVE
PURGE EXIT
VALVE

The reliability was compromised, although the Tug still meets the 0.97 goal for a 36-hour mission, by incorporating only one central computer in the Dat Management System (DMS). The use of only one central computer eliminates the requirement to develop a complex redundancy management scheme. The central c puter is charged with the responsibility of managing the remainder of the vehicle redundancies.

A 16-bit central computer was selected to minimize DDT&E costs since develop candidates currently exist. Programming a 16-bit machine will be more comple than a 32-bit machine but since the majority of the calculations requiring 24-32 bit accuracy are performed on the ground, this risk will be minimized.

The DMS is made fail safe by incorporating backup safing software in the Rem Data Processors (RDPS). The RDP'S are normally dedicated to IMU strapdown c culations. This backup software will safe the vehicle subsystems and stabili vehicle rates.

To the maximum extent possible the onboard software has been minimized consi ent with the requirements of Autonomy Level IV. The ground will perform all calculations required for state update, targeting, and mission planning. Res will be uplinked to the Tug. The onboard software will perform all calculat required for flight control, guidance, and subsystem control/redundancy management. Ground override capability is provided to augment onboard subsys control.

The Communication subsystem design is based primarily on the use of existing components. Only the minimum uplink/downlink services have been provided. A TM/uplink interface is provided to the Shuttle. There is no payload commur cations interface provided. NASA/DOD compatibility is achieved by component switching. The subsystem is redundant, so that no single point failure will result in loss of communications. This redundancy is achieved internal to tl units in most cases.

A DIGS IMU was selected to minimize initial DDT&E costs since this unit has been previously qualified on the Delta program. For the same reason the Orbi ing Astronomical Observatory (OAO) strapdown star tracker was utilized. The use of a strapdown star tracker constrains vehicle attitude, but since tl vehicle position/velocity are updated from the ground in Autonomy Level] relatively few attitude updates will be required, i.e., only required pr: main engine burns, and therefore the attitude will only be constrained fo periods of time.

Batteries were selected as the primary power source to minimize initial] costs. The selection of batteries was made possible by the relatively sh mission duration of 36 hours. The use of batteries imposes a weight pena. the vehicle even for short duration missions. This penalty grows with in mission duration. Two primary batteries are required to handle the vehic energy requirements and a backup battery is provided to provide safing c in case of a failure in the last active primary battery.

The Avionics Subsystem characteristics are tabulated in Table 2-2. A bl diagram of the system is given in Figure 2-7.

Program Option 3F increased the mission duration to 144 hours, changed t emphasis from low DDT&E to low total program cost, increased the autonom level from IV to III, required payload retrieval, and requires a payload munication interface (no checkout). These changes in requirements result the Avionics Subsystem changes shown.

Autonomous attitude update and targeting calculations were incorporated the onboard software. These calculations required the addition of additi computer memory.

The longer mission duration required the addition of another central con together with the System Control Unit required to manage the redundant c computers.

Additional Modular Interface Units (MIUs) were added to meet the increas interface requirements. The interface requirements increase due to the a of the fuel cells and associated tankage, the laser radar, and changes i propulsion subsystem. The additional interface units are added to the co control bus and do not require any additional development costs.

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Table 2-2

AVIONIC SUBSYSTEM CHARACTERISTICS - OPTION 3I

Subsystem	Qty	Weight (lb)	Power (W)
Data Management Subsystem (DMS)			
Central Computer	1	12	35
Remote Data Processor	2	20	64
Data Control Unit	1	8	12
Modular Interface Units			
BIU	10	28	95
PCU	14	37.4	42
DIU	2	5.1	3.2
RMU	16	46.8	52.8
DCU	16	42.8	25.6
SCU	4	11.7	4
Wire Harnesses (All except power)	50	93	--
Connectors	700	87.5	--
Total (DMS)		392.3	333.6
Guidance and Navigation Subsystem (G&N)			
DIGS IMU	2	100	240
Strapdown Startracker	2	32	12
Total (G&N)		132	252
Communication Subsystem (Comm)			
Omni Antenna	4	10	--
Microwave Circuitry	1	24	20
RF Multiplexer	1	4	--
Power Amplifier	2	16	74/144
STDN Transponder	1	26	32
SGLS Transponder	1	12	36
Command Decoder	1	5	5
PCM Encoder	1	3	4
Tape Recorder	2	40	25
Com Sec Equipment	2	12	14
Mod/Demod Processor	1	14	13
Total (Comm)		166	293
Instrumentation Subsystem			
Transducers and Sensors		26	107
Instrumentation Power Supplies	6	36	54
Total (Instr)		62	161
Electrical Power Subsystem			
Silver Zinc Primary Battery – 775 amp/hr	2	430	--
Silver Zinc Primary Battery 20 amp/hr	1	20	--
Nickel Cadmium Secondary Battery 15 amp/hr	1	37	--
Total (EPS)		487	
Electrical Power Distribution Subsystem			
Power Distribution Unit	1	20	30
Wire Harnesses	10	29	35
Total (EPDS)		49	65
Equipment Thermal Control			
Thermal Panels	--	71	--
Heat Pipes	--	26	--
Splice Mechanism	--	30	--
Radiation Shroud	--	16	--

Major Subsystem Characteristics Description

Data Management Subsystem (DMS)

- Central computer – 16-bit word length; 16,000 word memory; 2.6-μsec add time
- Remote data processors – 2 required – 16-bit word length, 2,000 word memory; 2.6-μsec add time
- 1-m bit data bus
- RDP's provide backup safety control
- Computers are MOS-LSI with plated wire memory
- PCU – electronic circuit breaker controls 16 power channels
- DIU – Serial digital interface between CMD/TLM bus and LRU's
- RMU – remote multiplexer accepts any combination of bilevel or analog input signals for 64 channels
- DCU – low-power switch controls up to 32 logic channels
- SCU – provides amplification from 20 mvdc to 5 vdc for 32 low-level analog channels
- MIU submodules are fabricated with beam lead devices mounted on ceramic substrates for maximum reliability

Guidance and Navigation Subsystem (G&N)

- DIGS IMU (space qualified); min DDT&E; 2 skewed packages (hexad)
- Strapdown startracker 8° x 8° FOV (space qualified on OAO)
- 10.0 nmi placement accuracy
- All-attitude capability

Communication Subsystem (Comm)

- Dual multiservice S-band system
- Compatible with STDN and AFSCF
- Redundant uplink and downlink
- Omni-antennas for all-attitude RF coverage
- Microwave circuitry selects antennas singly or in pairs
- RF channel multiplexer acts as channel separator for USB and SGLS transmit/receive signals
- Transponders provide tracking, ranging, transmission of PCM telemetry and reception of uplink data
- Power amplifiers provide the necessary effective radiated power from tug to supply a margin above minimum required performance at the receiver
- Modulator/demodulator processor is used for signal switching phase modulation (subcarriers) and demodulation of command subcarrier
- The command decoder detects, decodes, verifies, and distributes commands
- The PCM encoder combines the telemetry data into formats and clocks out the PCM data to be modulated on a subcarrier

Instrumentation Subsystem

- Existing sensors satisfy all measurement requirements

Electrical Power Subsystem

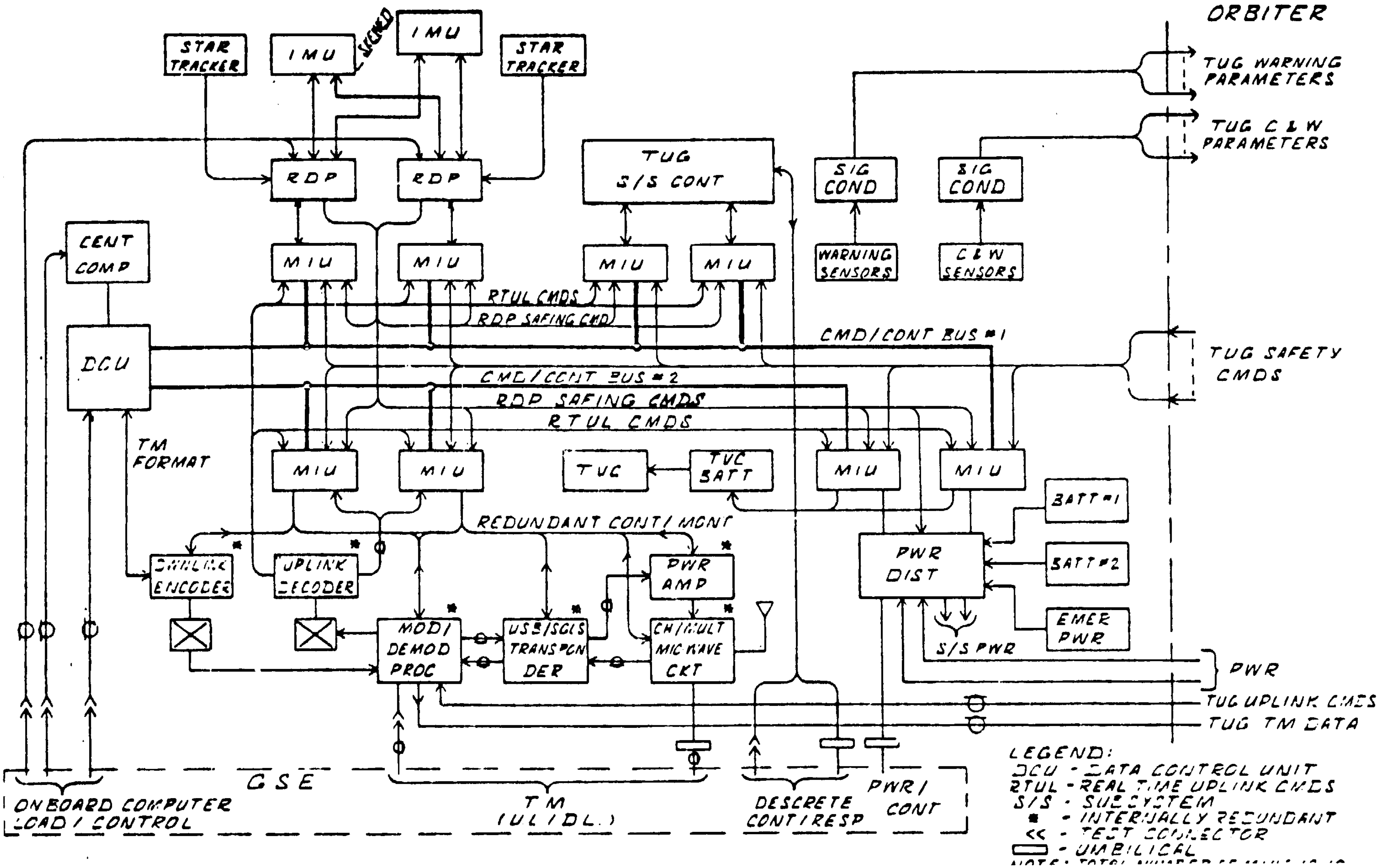
- AgZn batteries for primary and TVC power
- AgZn cells previously qualified – new case
- NiCd battery for backup power

Electrical Power Distribution Subsystem

- Electro-mechanical contractors and remote control circuit breakers driven by solid state drivers
- Redundant buses

Equipment Thermal Control

- Heat pipes have 1/2-in. square cross section with stainless steel wick and ammonia working fluid: 10-ft long sealed sections curved to fit vehicles
- Splice mechanism provides thermal conductivity between 10 ft sealed heat pipe sections to form circumferential hoop beneath panels
- Eight mounting panels 7 to 19 ft² with heat pipes thermally attached to rear surface. Low


ORBITER
TUG WARNING PARAMETERS
TUG C & W PARAMETERS
TUG SAFETY CMDS
STAR TRACKER
IMU
IMU
STAR TRACKER
RDP
RDP
TUG S/S CONT
SIG COND
SIG COND
WARNING SENSORS
C & W SENSORS
CENT COMP
DCU
MIU
RTUL CMDS
RDP SAFING CMD
CMD/CONT BUS #1
CMD/CONT BUS #2
RDP SAFING CMDS
RTUL CMDS
TM FORMAT
TVC
TVC BATT
BATT #1
BATT #2
EMER PWR
PWR DIST
S/S PWR
REDUNDANT CONT/MONT
UPLINK DECODER
PWR AMP
MOD/ DEMOD PROC
TRANSPON DER
CH/MULT MIC WAVE CKT
PWR
TUG UPLINK CMDS
TUG TM DATA
GSE
ONBOARD COMPUTER LOAD / CONTROL
TM (UL/DL)
DESCRETE CONT/RESP
PWR/ CONT
LEGEND:
RTUL - REAL TIME UPLINK CMDS
S/S - SUBSYSTEM
* - INTERNALLY REDUNDANT
- UMBILICAL

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A strapdown IMU utilizing tuned rotor gyros was selected to replace the DIG IMU in order to minimize the recurring costs. This IMU will also reduce the IMU weight and power requirements.

A laser radar was incorporated to meet the payload retrieval requirement. A laser radar was selected for the rendezvous/docking sensor in lieu of a radar/TV combination. The laser only option was selected to minimize the ve weight and due to the inability of the TV to control low earth orbit dockin operations. (This feasibility is still pending further definition of the TD capability.)

The primary batteries were replaced by fuel cells. The selection of fuel ce results in a significant weight savings for the longer duration missions. T fuel cells are provided and since either is capable of handling the total vehicle load a backup power source is not required. A separate AgZn battery been provided for the Thrust Vector Control (TVC) system to eliminate large peak power demands on the fuel cells and to keep these power transients off the main power busses.

The capability of interleaving payload/Tug TM data and the routing of paylo uplink commands from the Tug to the payload was incorporated into the Commu cations Subsystem. Payload checkout capability was not added.

The Avionics Subsystem characteristics for Option 3F are tabulated in Table A block diagram of the system is given in Figure 2-8.

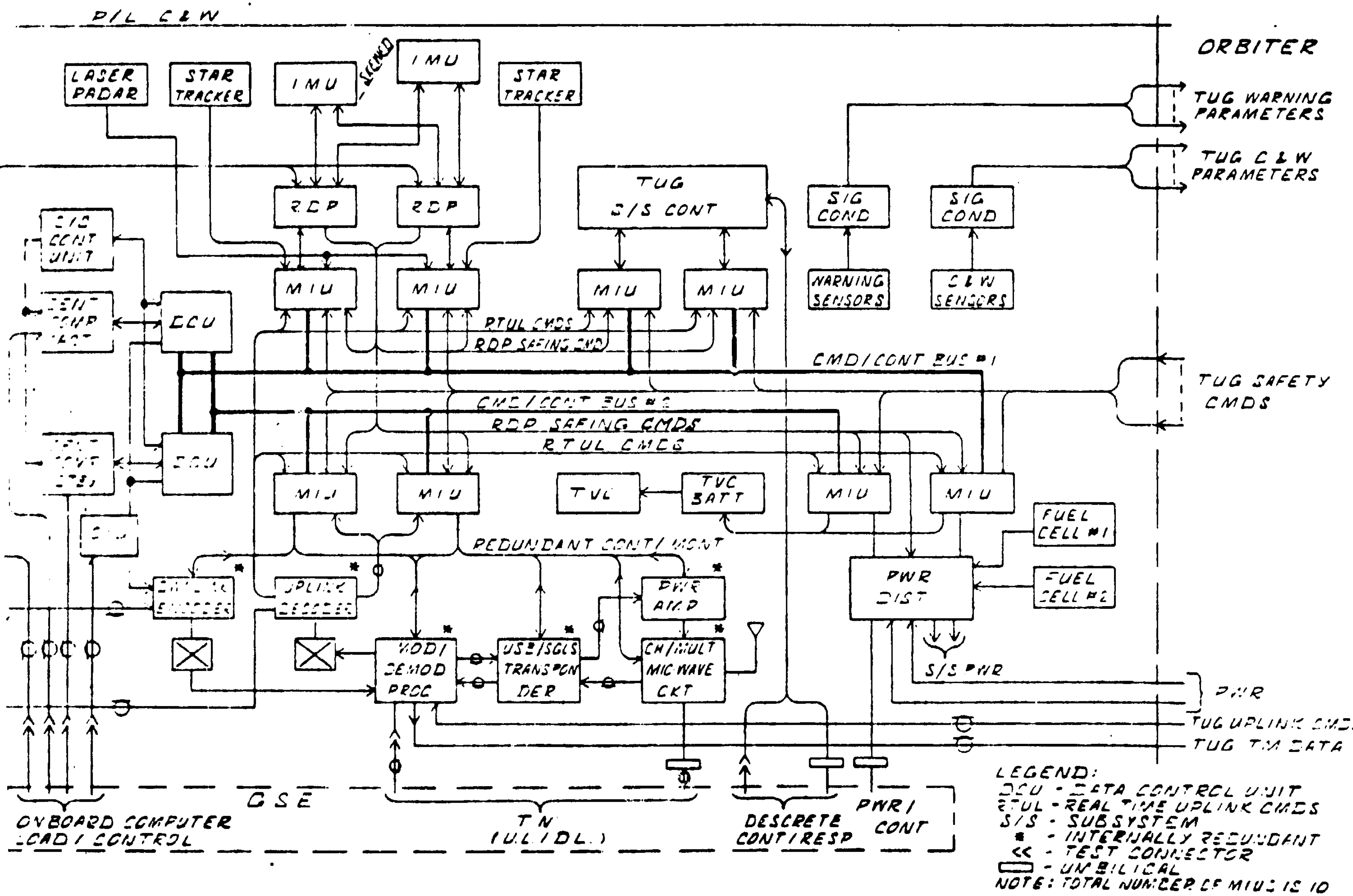
Avionics analysis and trade studies are discussed in detail in Volume 5.

Thermal control for the avionics modules in the front of the vehicle is provided by lightweight radiation shields. Shields are installed over the pane in the forward skirt to provide radiation protection when the orientation is toward the sun. Heaters are provided for orientation away from the sun. Heat pipes are used to pump heat from the hot side to the cold side when the vehi is oriented at right angles to the sun. Heat pipes are also used to control temperature of the mid skirt electronics to stabilize the temperature of the

Table 7

AVIONIC SUBSYSTEM CHARACTERISTICS - OPTION 3F

Subsystem	QTY	Weight (lb)	Power (W)	Major Subsystem Characteristics/Description
Data Management Subsystem (DMS)				• Control Computer – 16-bit word length; 24,000 word memory; 2.6 μsec add time
Central Computer	2	28	76	• 1-mbit data bus
System Control Unit	1	8	12	• SCU manages the redundant central computers
Data Control Unit	2	16	24	• Computers are MOS-LSI with plated wire memory
Computer Interface Unit	1	2.6	2	• PCU – Electronic circuit breaker controls 16 power channels
Modular Interface Unit				• DIU – Serial digital interface between CMD/TLM bus and LRU's
BIU	12	33.6	115.9	• RMU – Remote multiplexer accepts any combination of bilevel or analog input signals for 64 channels
PCU	22	59	66	• DCU – Low power switch controls up to 32 logic channels
DCU	20	40	32	• SCU – Provides amplification from 20 mvdc to 5 vdc for 32 low-level analog channels
RMU	20	53	66	• MIU – Submodules are fabricated with beam lead devices mounted on ceramic substrates for maximum reliability
DIU	2	5	3	
SCU	6	16	6	• Redundant remote data process computers – same as central computer but only 8,000 memory
Remote Data Processors	2	20	64	
Wire Harnesses (All Except Power)	50	114	--	
Connectors	700	87.5	--	
Total (DMS)		488.7	466.9	
Guidance and Navigation Subsystem (G&N)				
IMU (Tuned Rotor)	2	50	100	2 DOF tuned rotor gyros – low recurring cost – (2 skewed IMUs)
Strapdown Startracker	2	20	20	Strapdown startracker 8° x 8° FOV (space qualified · OAO)
Laser Radar	1	40	35	Automatic docking
Total (G&N)		110	155	All-altitude capability – 10.0 nmi placement Accuracy
Communication Subsystem (Comm)				
Omni Antenna	4	10	--	• Dual multiservice S-band system
RF Multiplexer	1	4	--	• Compatible with STDN and AFSCS
Power Amplifier	2	16	74/144	• Redundant uplink and downlink
STDN Transponder	1	26	32	• Omni-antennas for all-attitude RF coverage
SGLS Transponder	1	12	36	• Microwave circuitry selects antennas singly or in pairs
Command Decoder	1	5	5	• RF channel multiplexer acts as channel separator for USB and SGLS transmit/receive signals
PCM Encoder	1	3	4	• Transponders provide tracking, ranging, transmission of PCM telemetry and reception of uplink data
Tape Recorder	2	40	25	• Power amplifiers provide the necessary effective radiated power from tug to supply a margin above minimum required performance at the receiver
Comsec Equipment	2	12	14	
Mod Demod Processor	1	14	13	• Modulator/demodulator processor is used for signal-switching phase modulation (subcarriers) and demodulation of command subcarrier
Microwave Circuitry	1	24	20	
Total (Comm)		166	293	• The command decoder detects, decodes, verifies, and distributes commands
				• The PCM encoder combines the telemetry data into formats and clocks out the PCM data to be modulated on a subcarrier
Instrumentation Subsystem				
Transducers and Sensors		25	107	
Instrumentation Power Supplies	6	36	54	
Total (Instr)		61	161	
Electrical Power Subsystem				
H_2-O_2 Fuel Cell Battery-Advance Technology, KOH Electrolyte	2	66	--	• O_2:H_2 weight = 8:1 • 0.92 lb combined per kilowatt-hour
Silver-Zinc Primary Battery – 20 amp/hr	1	20	--	• AgZn primary battery for TVC power
Oxygen Tank – 203-lb Capacity at 900 psi	1	64	--	• Either fuel cell can supply total power
Hydrogen Tank – 25-lb Capacity at 250 psi	1	69	--	• Supercritical reactant storage
Oxygen Reactant	—	218	--	• Reactant tanks based on Gemini reactant supply tanks
Hydrogen Reactant	--	27	--	
Total (EPS)		464		
Electrical Power Distribution Subsystem				
Power Distribution Unit	1	21	50	• Electromechanical contactors driven by solid-state logic and drivers for bus control and protection
Wire Harnesses	10	30	36	• Solid-state remote power controllers used for switching of MIU feeders and for main bus
Total (EPDS)		51	86	
Equipment Thermal Control				
Thermal Panels	-	89	- -	• Heat pipes have 1.2-in. square cross-section with stainless steel wick and ammonia working fluid



…re 2-8. Avionics Block Diagram Program — Option 2E orientation operational constraints imposed by the on-board electronics the control requirements.

2.5 PROPULSION SUBSYSTEM SUMMARY (WBS 320-03-04)

The propulsion system is designed to the program requirements established f Option 3I and 3F and discussed in Section 1.

The selected subassemblies for the propulsion subsystem are defined to emphasize these requirements are summarized herein. The assemblies discusse herein are the main engine, main engine support, ACPS engine, and ACPS engi support.

2.5.1 Main Engine

The Category I RL10 engine was selected for the Option 3I and 3F Tugs. The principal performance geometric characteristics for this engine are tabulat below:

Characteristics of Category I RL10	
• Vac Thrust, lb	15K
• Engine Mixture Ratio	5.5
• Vac I_{sp}, sec	441.8
• Expansion Ratio	57:1
• Dry Weight, lb	293
• Length, in.	70.1
• Diameter, in.	39.5

2.5.2 Main Engine Support

The Option 1 main engine support assembly is basically comprised of hardwa subassemblies, i.e., feed, fill, and drain, etc. However, non hardware selections are also included in this category, i.e., main tank propellant orientation, and feedline and engine thermal conditioning. The main engine support selections are shown in Table 2-4.

Table 2-4

MAIN ENGINE SUPPORT SUMMARY

	Option 3	
	Initial	Final
Main Engine TVC	• McDonnell Douglas Electronics Co. Proposed Trident C-4 Electromechanical Actuators	→
Main Engine Feed	• LH_2 - 2.5 inch vacuum jacketed ducting tank to Parker 2 inch prevalve. 2 inch insulated S-IV design ducting prevalve to engine • LO_2 - 2.0 inch insulated ducting and Parker 2 inch prevalve S-IV design ducting prevalve to engine interface	→
Vent (Typ for LH_2 and LO_2)	• 6 valve configuration - 2 Calmec Vent and relief valves and 4 Calmec flight vent isolation valves. Vent ducting through Tug/Orbiter interface, 2.0 inch. Flight vent, 1 inch.	→
Fill and Drain	• LH_2 - 2.0 inch vacuum jacketed ducting and Parker 2 inch valve. • LO_2 - 2.0 inch insulated ducting and Parker 2 inch valve.	→
Pneumatics	• See Pressurization	• (Same as Option 2)
Propellant Utilization	• Closed loop with capacitance probes	→

Table 2-4

MAIN ENGINE SUPPORT SUMMARY (Continued)

	Option 3	
	Initial	Final
Pressurization	• S-IVB deriative ambient He for repress of LH_2 and LO_2, and expulsion of LO_2 Engine GH_2 bleed for LH_2 expulsion.	• S-IVB derivative c He and heater for repress. of LH_2 an LO_2, and expulsion LO_2.
Propellant Orientation	• ACPS thrusting using two aft firing thrusters. Variable time depending on quantity of LH_2 in tank.	⟶
Engine and Feedline Conditioning	• Trickle bleed propellants through engine and feedline. Propellants vented overboard.	⟶
LO_2 Abort Dump	• 3.0 inch insulated ducting and parallel Fairchild butterfly valves.	⟶

The Option 1 main propulsion system schematic is shown in Figure 2-9. The schematic shows all of the Tug main propulsion subassemblies, plus the main propellant tank insulation vent and purge. In addition, the schematic shows the fluid lines and hardware located in the orbiter payload bay and orbiter payload bay and orbiter aft section which are required to support the Tug.

The Option 1 Tug features a Category I RL10 main engine with GH_2 bleed for LH_2 tank pressurization, and an ambient helium assembly for repressurization and LO_2 expulsion. Also shown are the vent, main engine feed, fill, and drain, LO_2 suborbital dump, and LH_2 horizontal drain subassemblies.

The orbiter side of the interface shows the LH_2 tank purge helium provisions and the ambient helium fill, fill and drain, main tank vent, orbital dump, and LO_2 suborbital abort dump line provisions.

The Option 3F main propulsion system schematic is shown in Figure 2-10. The schematic shows all of the Tug main propulsion subassemblies, plus the main propellant tank insulation vent and purge. In addition, the schematic shows the fluid lines and hardware located in the orbiter payload bay and orbiter aft section which are required to support the Tug.

The Option 3F Tug features a Category I RL10 main engine with GH_2 bleed for LH_2 tank pressurization, and a heated helium assembly for LH_2 and LO_2 repressurization and LO_2 expulsion. Also shown are the vent, main engine feed, fill, and drain, LO_2 suborbital dump, and LH_2 horizontal drain subassemblies.

The orbiter side of the interface shows the LH_2 tank purge helium provisions and the ambient helium fill, cold helium fill, fill and drain, main tank vent, orbital dump and LO_2 suborbital abort dump line provisions. This Tug also requires connections and lines for LH_2 and LO_2 fuel cell reactants.

2.5.3 ACPS

The Option 3I ACPS system is of a simple monopropellant blowdown design. Propellant (N_2H_4) is stored under pressure in three spherical tanks. The tanks are half loaded (by vacuum loading scheme) with propellant, the other half of the tanks, separated from the propellant by an elastic diaphragm, containing nitrogen gas under pressure. A schematic of the ACPS is shown in Figure 2-11.

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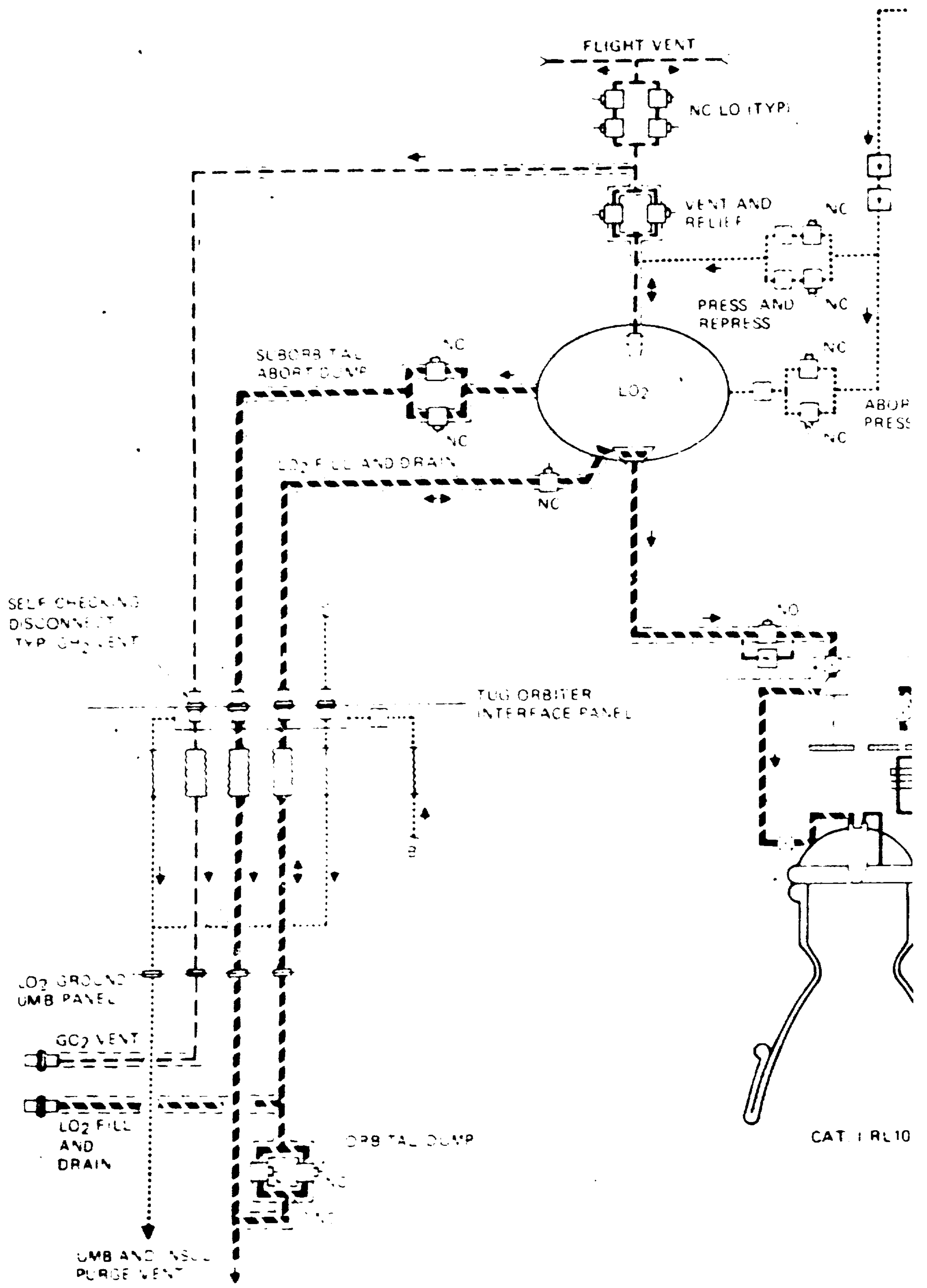

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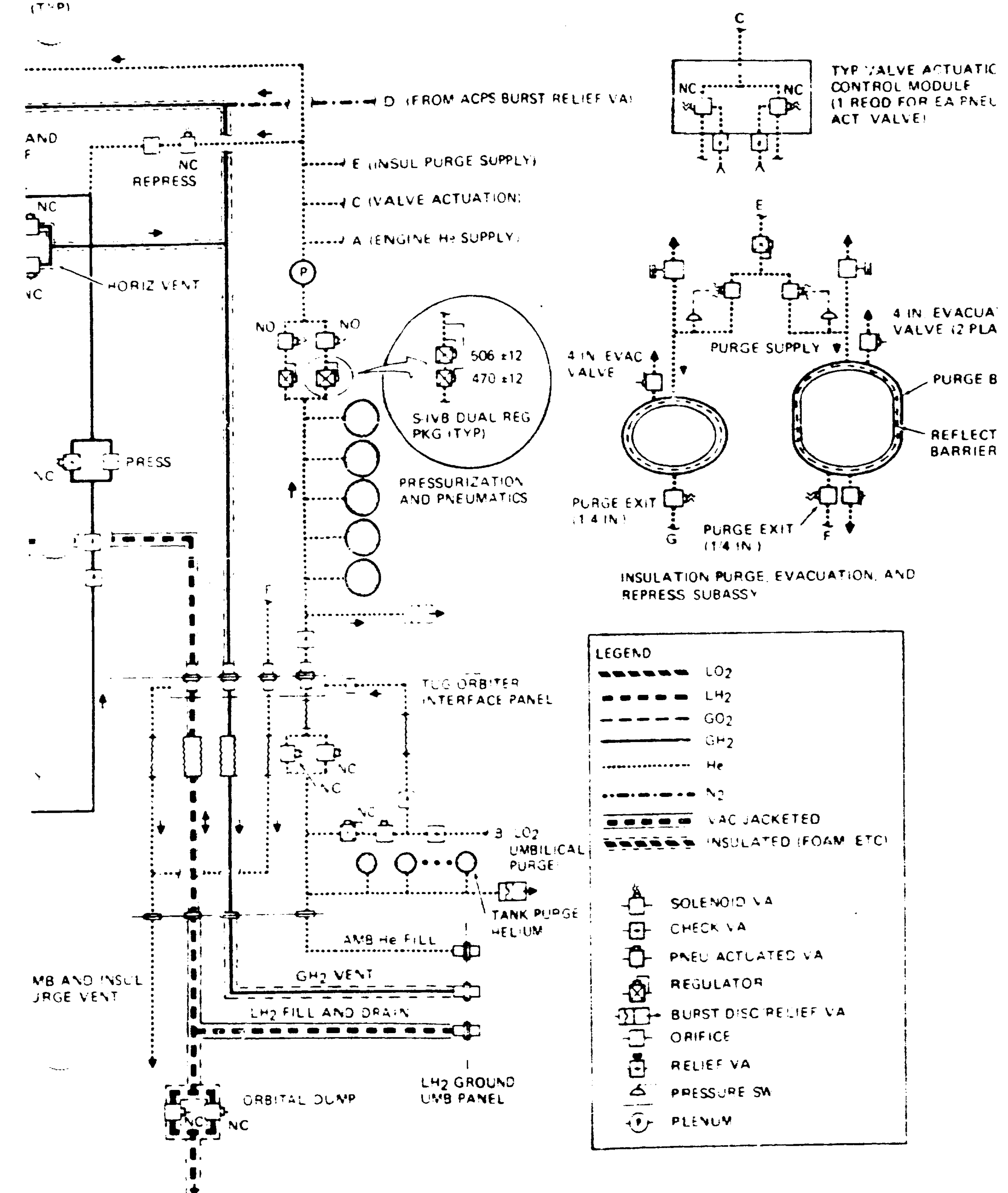

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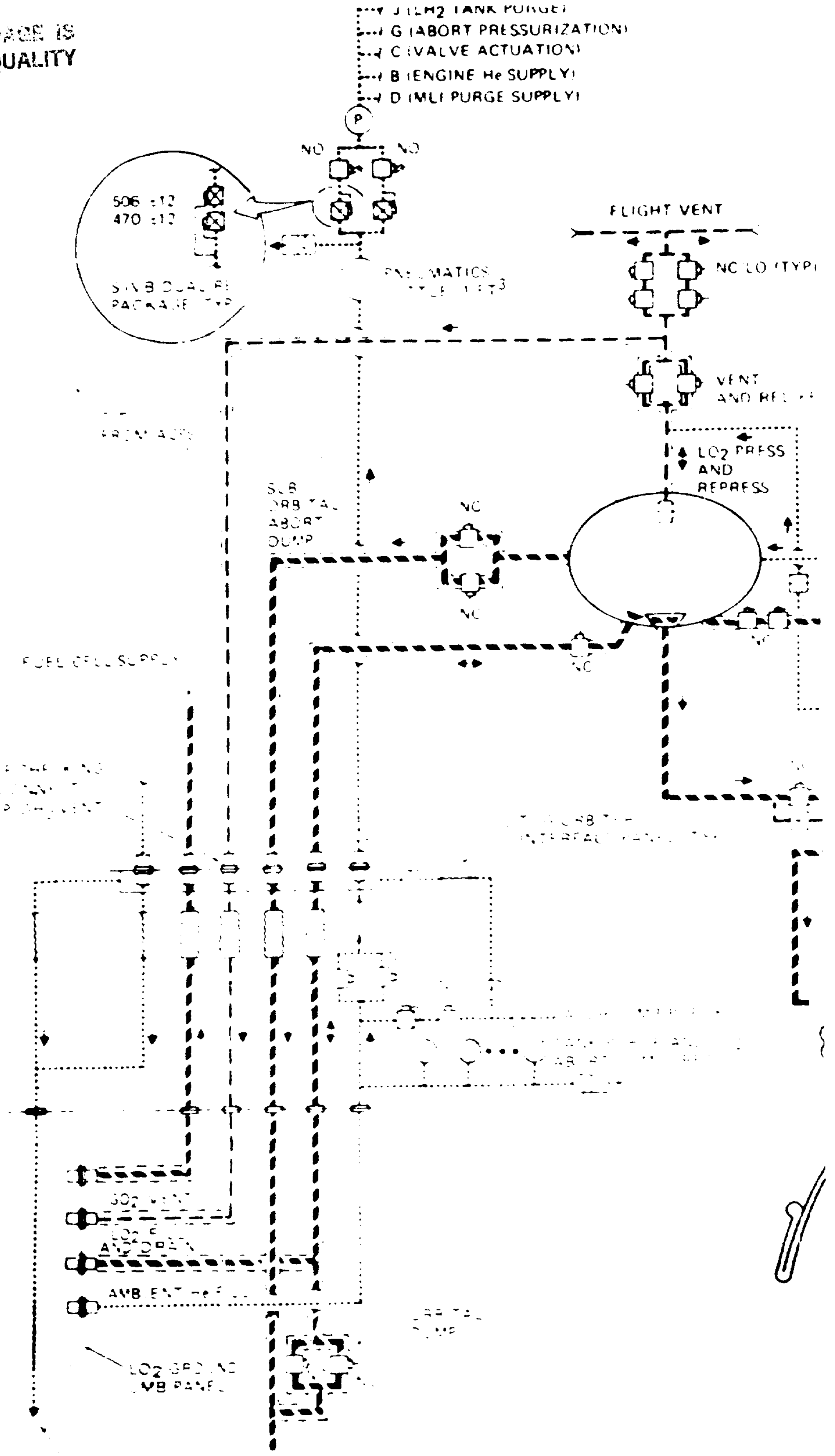

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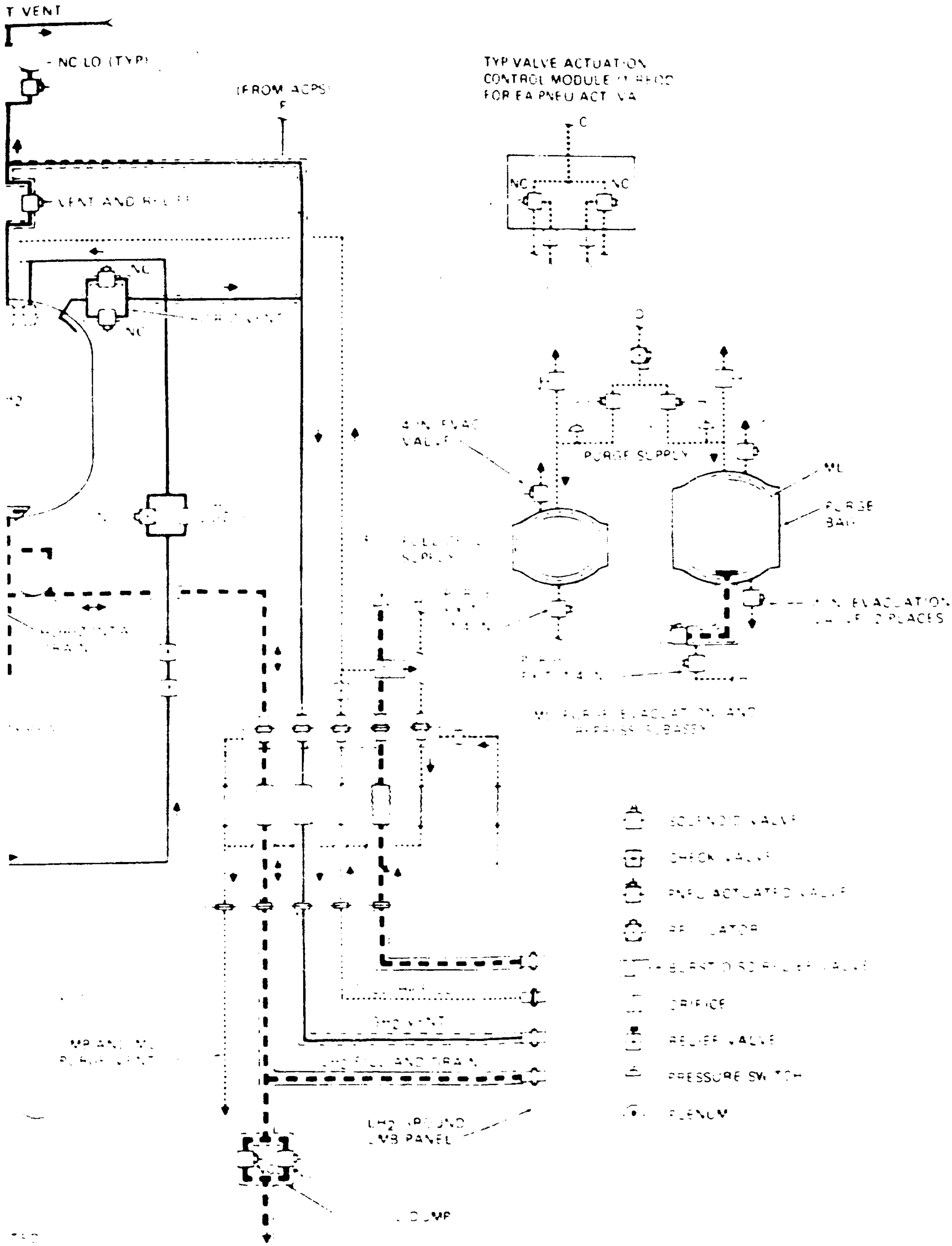

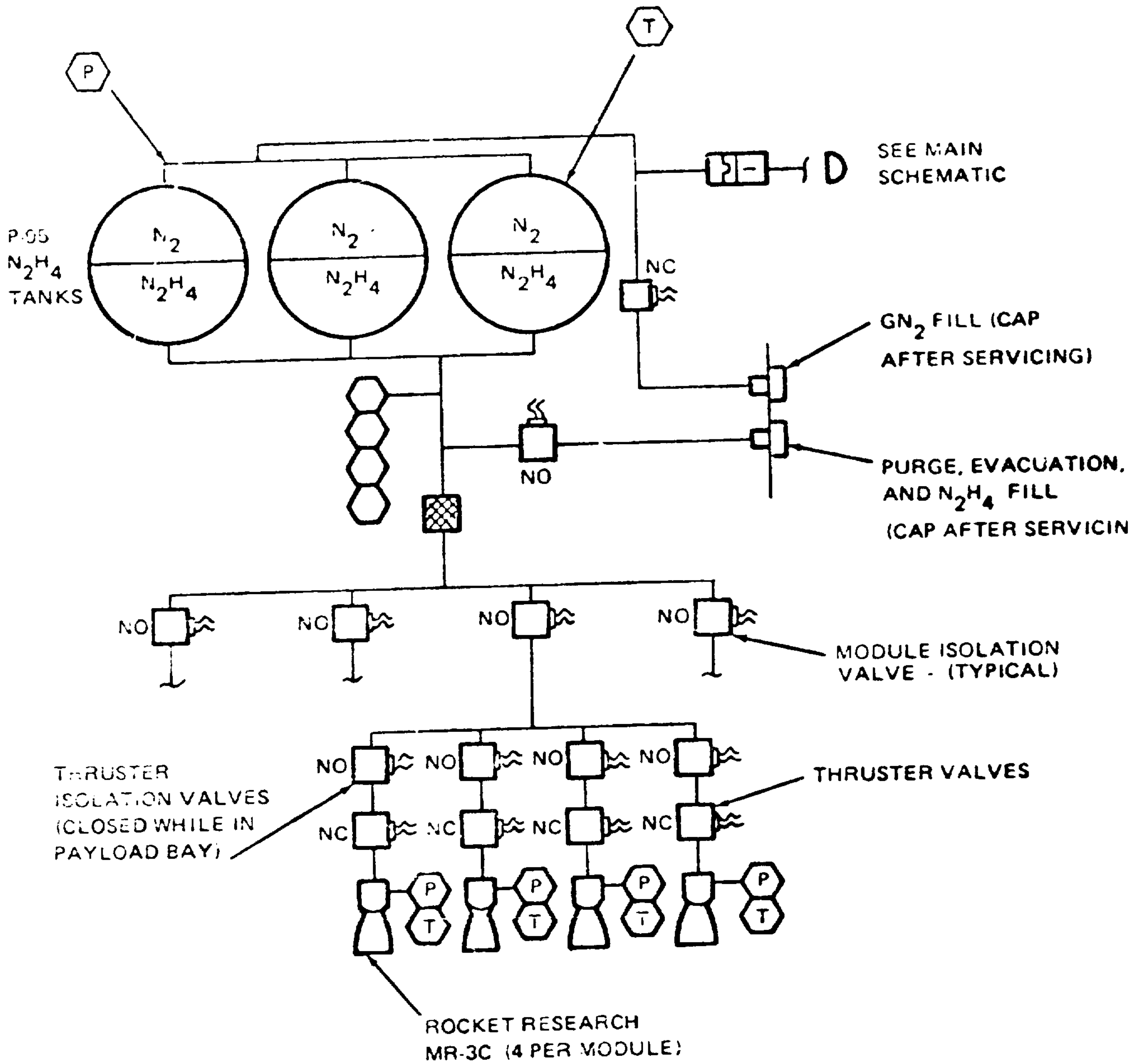

Figure 2-11. ACPS Schematic – Option 3I

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Propellant is directed to each of four thruster pods, each pod containing four thrusters, via a propellant feed system. The thruster arrangement aff 6 degrees of freedom for attitude control. A network of isolation valves i propellant feed system provides fail operational/fail safe performance.

The major performance characteristics of the system are presented in Table 2-5 followed by a description and source identification of the major components in Table 2-6. The schematic shows the propellant tank manifold feed system to the ACPS thrusters, and the APS thruster module isolation va required to achieve fail operation/fail safe reliability. The schematic als shows provisions for filling and draining propellants and pressurization w nitrogen.

The Option 3F ACPS system utilizes bipropellants (MMH/N2O4) pressurized by regulated helium supply. The helium is stored in a 1.0 cu ft high pressure sphere and regulated to the propellant tanks by a network of redundant regu lators. The propellants are contained within teflon bladders inside spheri propellant tanks. The propellants are initially vacuum loaded and then pres surized by the regulated helium. Propellant is directed to each of four thruster pods, via a propellant feed system. A network of isolation valves the propellant feed system provides fail operational/fail safe performance. Each thruster pod contains four thrusters; two 90 lbf axial thrusters and two 22 lbf tangential thrusters.

The major performance characteristics of the system are presented in Table followed by a description and source identification of the major components Table 2-8.

The schematic of the Option 3F ACPS system with instrumentation is presente Figure 2-12. The schematic shows the fluid diagram as well as the electric circuitry required for the regulated helium pressurization system. Illustra are the propellant tank manifolding, feed system to the thrusters, and the thruster and thruster module isolation valving required to achieve fail operational/fail safe reliability. The schematic also contains provisions f filling and draining propellants and for loading ambient helium. A detailed discussion of system operation is contained in Volume 5.

Table 2-5

ACPS PERFORMANCE SUMMARY

Maximum Total Impulse Capacity	65,000 lbf/sec
Maximum Total Impulse Required	50,700 lbf/sec
System Loaded Weight at Maximum Total Impulse Capacity	440 lbm
System Loaded Weight at Maximum Total Impulse Required	380 lbm
Thrust Level of Thrusters	29.8 lbf blowdown to 17 lbf
Degrees of Freedom of Attitude Control	6
Fail Operationa/Fail-Safe ACPS	Yes
Thruster Arrangement	4 Pods of 4 each
Total Number of Thrusters	16
Number of Propellant Tanks	3

Table 2-6

ACPS MAJOR COMPONENT DESCRIPTION

Thrusters:	
Number Required	16
Model Number	MR-3C
Manufacturer	Rocket Research
Previous Programs	Transtage
Propellant Tanks:	
Number Required	3
Previous Program	P-95
Diaphragm Material	AFE-332
Size	22 in. Dia Sphere
Volume (each)	5,600 cu in.
Operating Pressure	350 psia
Burst Pressure	700 psig
Empty Weight (each)	14.35 lbm

Table 2-7

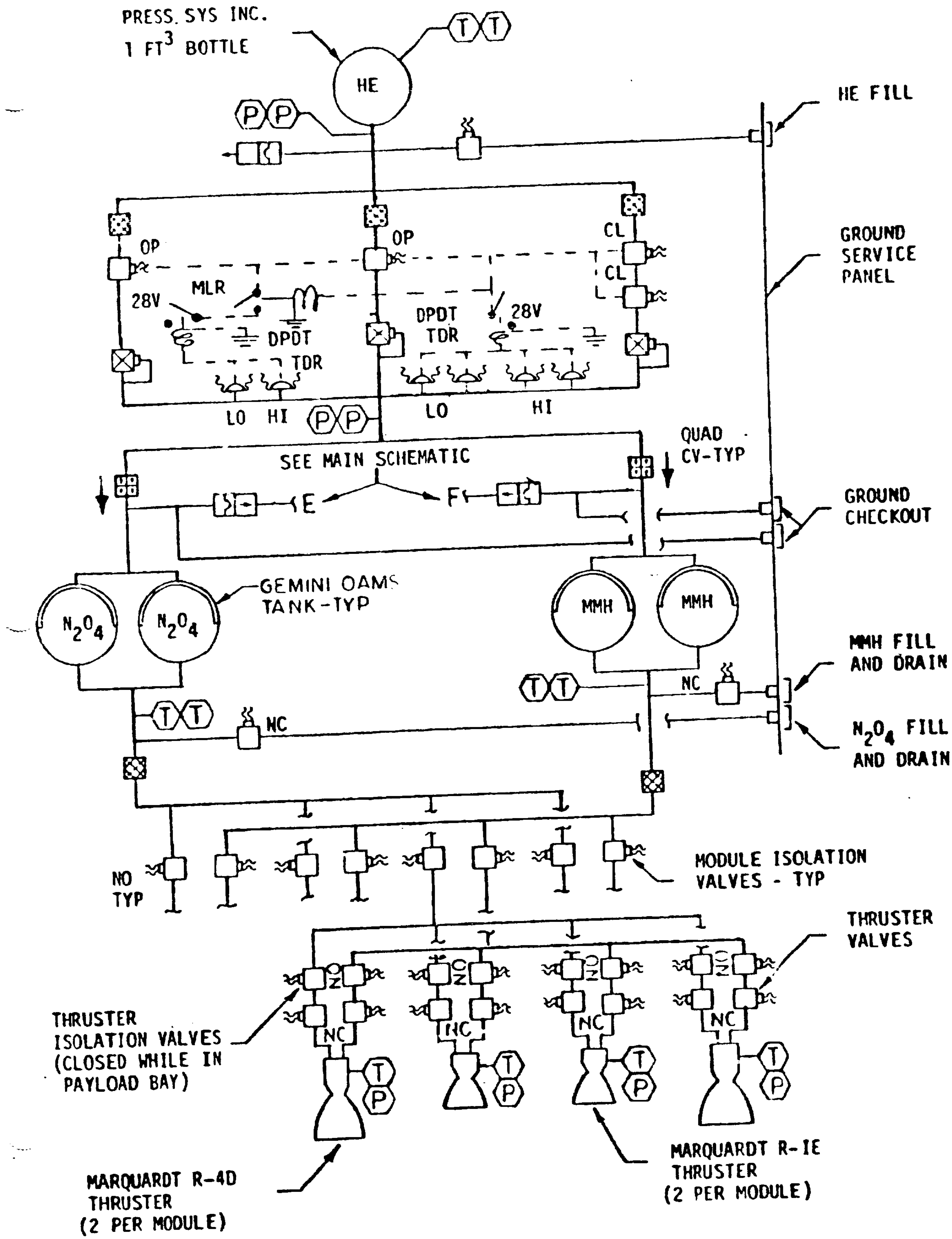
ACPS SYSTEM PERFORMANCE SUMMARY

Maximum Total Impulse Capacity	176,000 lbf/sec
Maximum Total Impulse Required	148,000 lbf/sec
System Loaded Weight at Maximum Total Impulse Capacity	930 lbm
System Loaded Weight at Maximum Total Impulse Required	820 lbm
Thrust Level of Thrusters	90 lbf and 22 lbf
Degrees of Freedom of Attitude Control	6
Fail Operational/Fail-Safe ACPS	Yes
Thruster Arrangement	4 pods of 4 each
Total Number of Thrusters	16
Number of Propellant Tanks	4

Table 2-6

ACPS SYSTEM MAJOR COMPONENT DESCRIPTION

Axial Thrusters:	
Number Required	8
Model Number	R-4D
Manufacturer	Marquardt
Previous Program	Apollo SM
Tangential Thrusters:	
Number Required	8
Model Number	R-1E
Manufacturer	Marquardt
Previous Program	MOL
Propellant Tanks:	
Number Required	2 each, Fuel and Oxidizer
Previous Program	Gemini OAMS
Bladder Material	"CO-Dispersion" Teflon
Size	20 in. Dia Sphere
Volume (each)	4,130 cu inches
Operating Pressure	224^{+7}_{-4} psia
Burst Pressure	670 psia
Empty Weight	9.5 lbm
Helium Bottle:	
Number Required	1
Previous Program	PT4
Size	15 in. Dia Sphere
Volume	1,728 cu inches
Operating Pressure	3,600 psia
Burst Pressure	7,200 psig
Empty Weight	21.8 lbm
Helium Regulator:	
Number Required	3
Model Number	6890
Manufacturer	Consolidated Controls
Previous Program	MM III PBPS
Regulator Outlet Pressure	224^{+7}_{-4} psia
Inlet Operating Pressure	3,640/450 psig
Inlet Burst Pressure	5,460 psig



THRUSTER MODULE

2.6 SHUTTLE INTERFACE (WBS 320-05-0?)

The Shuttle Orbiter/Tug Interface (Figure 2-13) is composed of the extensio of major Tug subsystem to the Orbiter as are necessary for performing the major preflight, flight, and post flight operations. These operations are:

- Preflight Ground Testing and Checkout
- Launch Phase Monitoring
- Pre-release Checkout
- Activation of Subsystems
- Deployment of the Tug/Payload
- Monitoring in Orbiter Proximity
- Monitoring during Tug Mission Operation
- Command/Control in Orbiter Proximity
- Subsystem Deactivation
- Retrieval of the Tug/Payload
- Stowage of the Tug/Payload
- Passivation and Safing of Tug/Payload
- Return Flight Monitoring
- Safety Provisions
- Ground Support Interfacing

The Shuttle Orbiter/Tug interface represents the provisions for mating two major systems — each of which is capable of independent operation when part in space. While mated, the Tug is dependent to a degree upon the support ca bility of the Orbiter and of the ground through the Orbiter. Although passi during most of the launch and landing periods, continuous safety and subsys status monitoring is sustained by the Orbiter crew.

The Shuttle Orbiter conducts many missions which do not include the Tug, ho ever, and it is essential that the Tug interfaces produce minimum design ar operational impacts upon the Orbiter. In order to minimize these impacts, t Tug ancillary hardware is designed for easy installation and removal. The cabin provisions consist of a dedicated portion of the Mission Specialist Station and multiplexed interfaces with the Shuttle Orbiter Data Management computation, and display equipment. This allows accessing and display of Tı

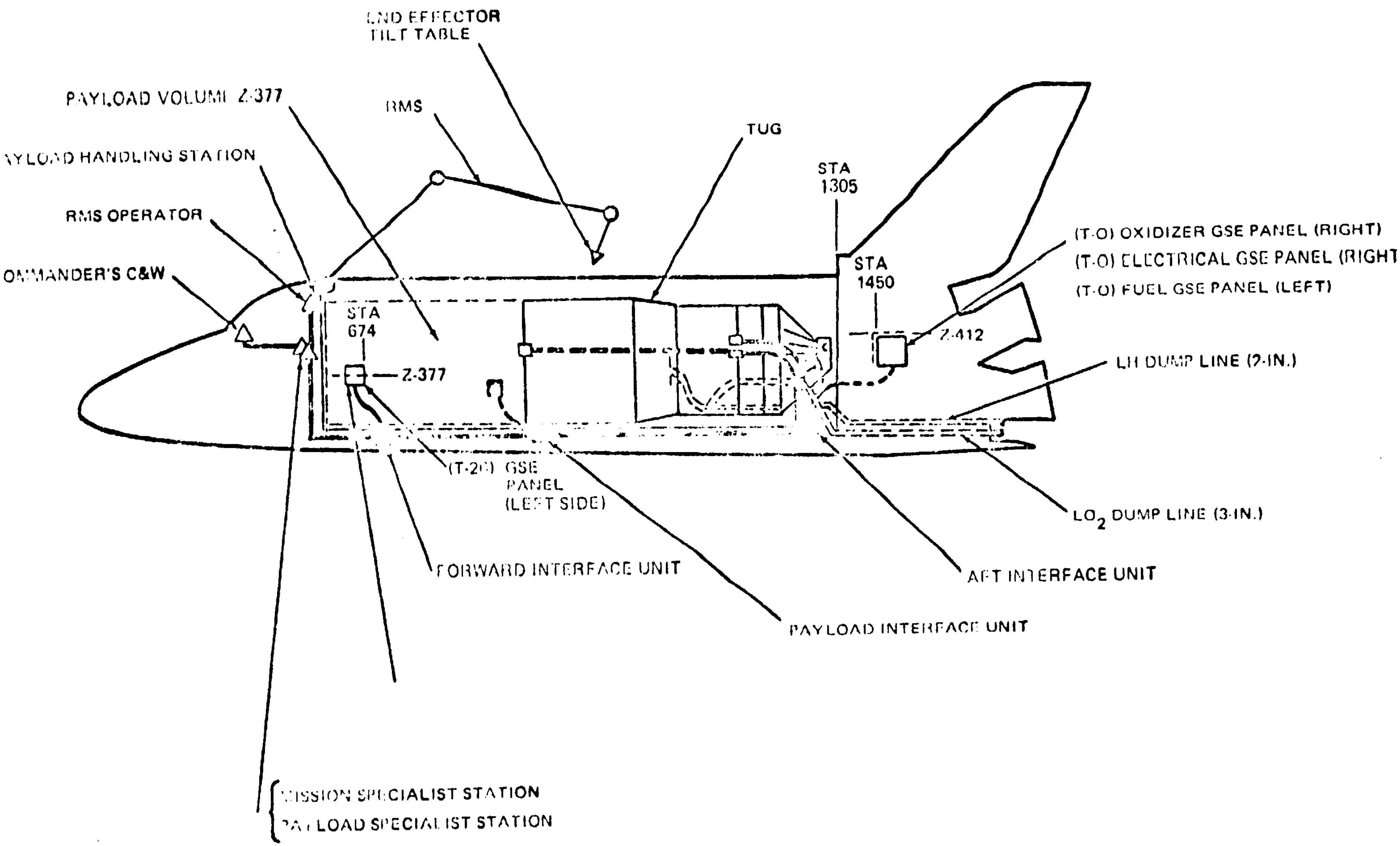


Figure 2-13. Shuttle/Tug Interfaces Hardware Location

dedicated panel section, sufficient control to take corrective action.

The principal functions and hardware groups as listed below are shown in Figure 2-13.

FUNCTIONS

- Operations (listed above and discussed in Section 6)
- Safety (discussed in Volume 7)
- Structural/Mechanical Support (attachments, mountings, manipulatio provisions)
- Fluid/Propulsion Support (fill/drain/vent/purge/abort provisions)
- Thermal Conditioning Support (temperature control provisions)
- Avionics Support (electrical/electronics, checkout/monitor/control provisions, with data management, communications, electric power, guidance/navigation/control subsystems)
- Payload Support (checkout/monitoring, control, caution/warning, safing, electrical power circuits routed through the Tug)

HARDWARE GROUPS

- Tug Support Structure (tilt cable)
- Tug Support Attachments (hard points, latches, locks, support fram adapters)
- Remote Manipulating System (RMS arm is part of Orbiter mechanisms, Tug-unique end effector with TV and lighting is charged to Tug sup
- Fill/Drain/Vent/Purge/Abort Line Assemblies (includes vacuum-jacke low temperature lines and purging provisions)
- Fluid Panels and Retraction Mechanisms (purging provisions, locks, actuators, drives, drive controls)
- Electrical/Electronics Support (instrumentation, sensors, caution warning circuits, electrical cables/connectors, interface units, ju tion boxes, test points, inhibit functions/circuits/buses, drive control electronics, TV, lighting)

Option 3F is 1780 lb respectively. This weight is detailed in the WBS Weight Statement in Volume 5. The hardware groups are described in Volume 5, ection 4.

2.7 PAYLOAD INTERFACE SUMMARY (WBS 320-03-01-06)

2.7.1 Option 3 Initial Payload Interface

The payload interface structure is shown in Figure 2-1. It consists of a square frame attached to an eight member open truss. The truss was sized by a combination of maximum payload weight and Shuttle flight loads. The payload loads are transmitted through the truss into the Tug at same forward frame hard point as the forward tank support. Structural latching between Tug and payload occurs at the corners of the square frame by means of spring loaded pneumatic operated latches. The payload side of the interface consists of a ring whose diameter is equal to the diagonal distance across the square frame. A detailed description of this interface is given in Volume 5, Section 4.3, Option 1.

There is a minimum electrical (avionics) interface between the payload and this tion, consisting of caution and warning signals required by the Shuttle and routed through the Tug/Tug orbiter interface.

Operationally, deployment is achieved by first mechanically disconnecting the electrical interface, then pneumatically unlatching the four corner latches, all this while the Tug is limit cycling for fine hold, the Tug then backs away from the payload.

2.7.2 Option 3 Final Payload Interface

To phase the payload interface to the final configuration the initial interface structure is removed from the stage by detaching the eight truss members from the forward frame hard points.

The Option 3 final payload interface structure is shown in Figure 2-2. It consists of four combination docking/structural latches. These latches are spring loaded pneumatically operated and located at the corners of a shock strut mounted square frame. The eight struts are pneumatically deployed, hydraulically retracted gas shock absorbers. They are structurally locked in the retracted position by means of pneumatically operated spring loaded inte ball latches. The interface structure was sized by a combination of maximum payload weight and shuttle flight loads. The payload loads are carried throu the shock struts into the Tug at the same forward frame hard point as the fo ward tank supports. The shock absorbing characteristics of the shock struts were determined from expected docking loads derived from established maximum docking parameters such as allowable closing velocities, misalignments, etc. The docking system is capable of retrieving spinning satellites and despinni them using the friction between the docking latches and the payload docking ring. Pre-deployment spin-up and post retrieval indexing is provided by mean of an electro/mechanical spin system. Details of this system are presented i Volume 5, Section 4.3. The interface diameter is variable from 8 to 13 ft by manually interchanging the square frame member.

The docking system is designed to meet or exceed the following contact condition requirements.

Radial Misalignment	±6 inches
Longitudinal Velocity	0.1 to 1.0 FPS
Lateral Velocity	0.3 FPS
Angular Misalignment	±3 degrees
Angular Rate	±2.4 deg/sec
Spin Rate	up to 100 RPM

The electrical (avionics) interface consists of the necessary wires, connect and fittings to provide relay of payload caution and warning parameters and normal payload telemetry data for shuttle transmission while in the orbiter bay. In addition, the payload may demand up to 300 watts of continuous power while attached to the Tug.

Operationally, payload deployment is achieved by first extending the docking frame. This motion assists in disconnecting the electrical interface as the frame moves away from the stage. Once extended, the corner latches are opene The frame is then retracted and the Tug, which has been limit cycling for fi hold, backs away from the payload.

... payload, once proper Tug/payload orientation has been established with the laser radar guiding the ACPS, the docking frame is extended. The Tug then approaches the payload at the prescribed rate and one or more docking latches contact the payload's interface ring. The latches are individually triggered to the capture position as they make contact. The spin/indexing system is then moved into contact with the payload I/F ring, and the payload rotated to proper orientation for remake of the electrical interface. The indexing system is retracted and the latches moved to the structure locked position. The frame is then retracted and the ball latch latched.

2.8 AUXILIARY (KICK) STAGE SUMMARY (WBS 320-04-01)

The use of a kick stage (Figure 2-14) on four of the NASA planetary missions (19, 20, 21, and 23), with both initial and final Tugs, and one DOD mission (11a), with the initial configuration, allows these missions to be flown in a reusable mode with the Tug. These were the only missions where the use of a kick stage was required.

A range of acceptable kick stage sizes was established parametrically for the NASA missions. A survey of existing solid rocket motors was made in an attempt to identify an existing stage which could be utilized for the Tug missions. Several constraints, such as stage length and thrust to weight were used in making the final selection. The stage most nearly meeting the requirements was the second stage of the Polaris A3. This stage is considerably over sized for the DOD mission but can be flown in an off optimum manner. The use of a smaller kick stage was not considered cost effective.

Since it is only used on one flight with the initial Tug, design details of this stage are classified and may be found in the confidential document Rocket Motors Manual (U), Unit 411, Chemical Propulsion Information Agency, John Hopkins University.

In an attempt to minimize changes to a standard Tug/payload Interface, the Tug/payload/kick stage interface shown in Figure 2-14 was conceived. By replacing the standard Tug/payload interface truss with the one shown, the Tug/payload interface remains the same, with the exception that the interface plane moves forward. The longer struts allow the kick stage to interface

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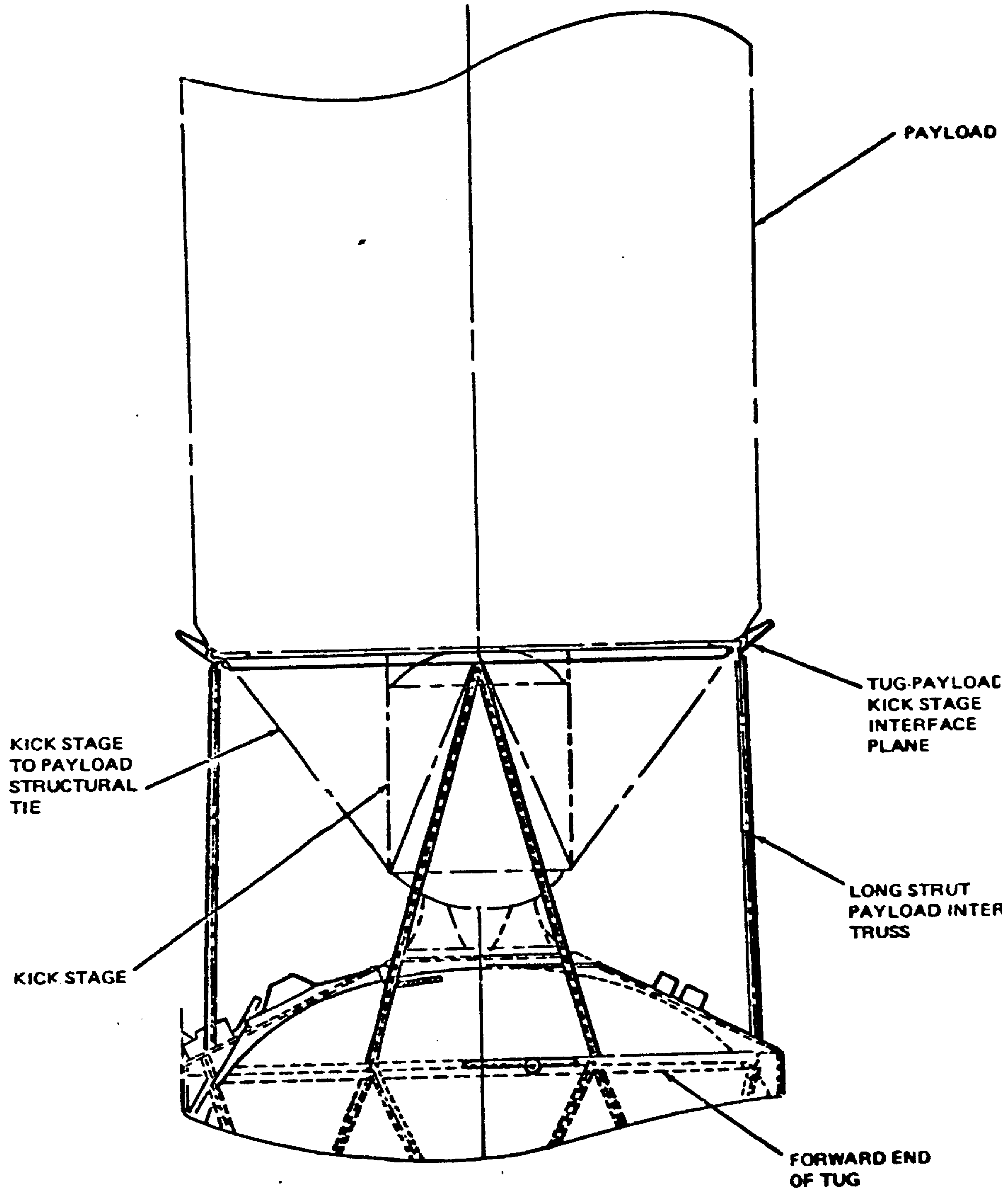

Figure 2-14. Tug-Payload – Kickstage Interface

directly with the payload interface ring. There is no direct structural interface between the Tug and kick stage. The longer struts were designed by the combined payload kick stage loads. Electrical interface between Tug and kick stage is accommodated through the Tug/payload electrical interface panel. In essence, the kick stage appears as part of the payload to the Tug.

Operationally, the Tug separates from the payload/kick stage combination in the same manner as separating from a payload. The Tug provides the proper flight path angle prior to separation. After an appropriate separation distance is established, the kick stage is fired completing the payload velocity requirement. The kick stage must provide thrust vector control during its burn. The tug is then free to return to the Shuttle.

2.9 MASS PROPERTIES SUMMARY

2.9.1 Weight

The weights are summarized in Table 2-9 for Option 3 initial and Table 2-10 for Option 3 final. The weight breakdown is structured after the WBS breakdown and contains a ten percent contingency on the total dry weight. A new element has been added called margin, which has permitted the weight analysis to continue to be refined up to the last moment and not force an iteration of the programmatics. This margin although small, 2.7 percent for Option 3 initial and 1.0 percent for Option 3 final have increased confidence that the stage mass fraction can be achieved.

The weights presented herein are based upon the design defined in Volume 5, Book 3, Section 2. Additional weights and definition is included in the above volume, in Section 3, along with total vehicle mass properties.

2.9.2 Center of Gravity

Figures 2-15 and 2-16 illustrate the limits for the three selected mission points for Orbiter center of gravity landing constraints. The only cg outside these limits is the fully loaded Tug with interface provisions. This cg constraint is applicable during abort for subsonic and hypersonic flight. This constraint is met by dumping approximately 20 percent of the LOX propellant during main orbiter burn with the remaining LOX dumped 30 seconds after MECO.

Table 2-9

OPTION 3 INITIAL

WEIGHT STATEMENT FOR DEPLOYMENT MISSION

Structure		2,621		
Fuel Tank and Supports			951	
LOX Tank and Supports			294	
Body Structure			1,082	
Shell				87
Supports				20
Thrust Structure			113	
Meteoroid Protection			69	
Payload Interface			112	
Thermal Protection		204		
Fuel Tank Insulation			101	
LOX Tank Insulation			15	
Insulation Purge			85	
Control System			3	
Avionics		1,457		
Data Management			222	
Guidance and Control			132	
Communication			166	
Instrumentation			215	
Electrical Power Source			487	
Power Distribution and Control			90	
Equipment Thermal Control			144	
Propulsion		1,566		
Main Engine			293	
Main Engine Support			1,134	
ACPS Engine			66	
ACPS Engine Support			73	
Dry Weight	5,848			
Contingency		585		
Margin		173		
Total Dry Weight	6,606			
Residuals		864		
Burnout Weight	7,470			
Usable Propellant (MR 4.5/1)			51,212	
ACPS			236	
Misc			416	
Inflight Losses		51,864		
Orbiter Launch Weight Less Payload	59,334			
Payload		3,500		
Orbiter Launch Weight	62,834			
Orbiter Interface - Cargo Bay		1,627		
Orbiter Interface - Remaining		270		
Misc		269		
Ground Launch Weight	65,000			

Table 2-10

OPTION 3 FINAL

WEIGHT STATEMENT FOR RETRIEVAL MISSION

Structure		2,720		
Fuel Tank and Supports			951	
LOX Tank and Supports			294	
Body Structure			1,063	
Shell				878
Supports				185
Thrust Structure			113	
Meteoroid Protection			69	
Payload Interface			230	
Thermal Protection		308		
Fuel Tank Insulation			140	
LOX Tank Insulation			80	
Insulation Purge			85	
Control System			3	
Avionics		1,303		
Data Management			277	
Guidance and Control			110	
Communication			166	
Instrumentation			219	
Electrical Power Source			270	
Power Distribution and Control			99	
Equipment Thermal Control			162	
Propulsion		1,313		
Main Engine			293	
Main Engine Support			792	
ACPS Engine			78	
ACPS Engine Support			150	
Dry Weight	5,646			
Contingency		565		
Margin		43		
Total Dry Weight	6,254			
Residuals		906		
Burnout Weight	7,160			
Usable Propellant			54,661	
ACPS			461	
Misc			838	
Inflight Losses		55,960		
Orbiter Launch Weight	63,120			
Orbiter Interface - Cargo Bay		1,510		
Orbiter Interface - Remaining		270		
Misc		100		
Ground Launch Weight	65,000			

Tug Mass Fraction = 0.866

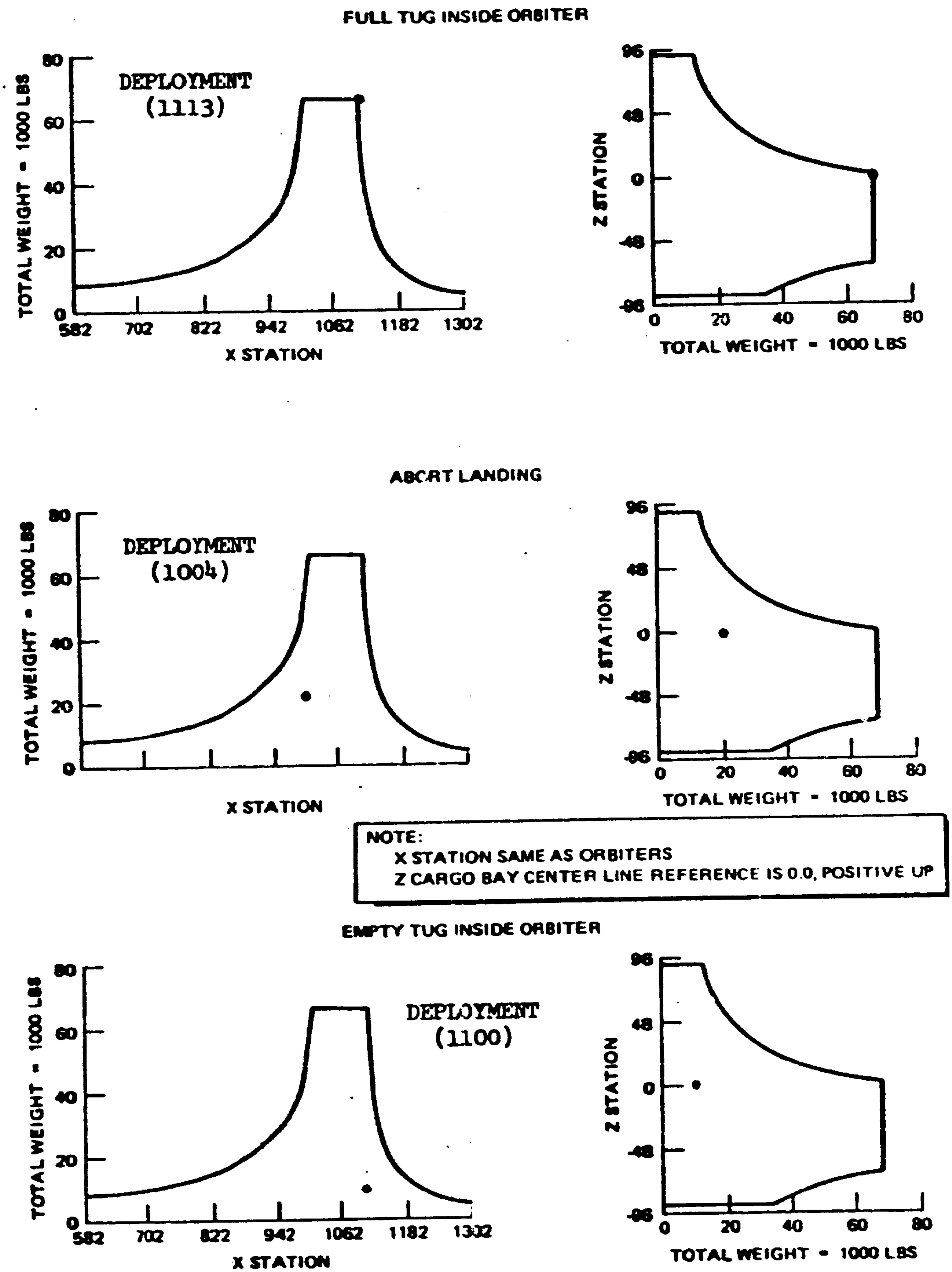

Figure 2-15. Orbiter Center-of-Gravity Limits – Option 3I

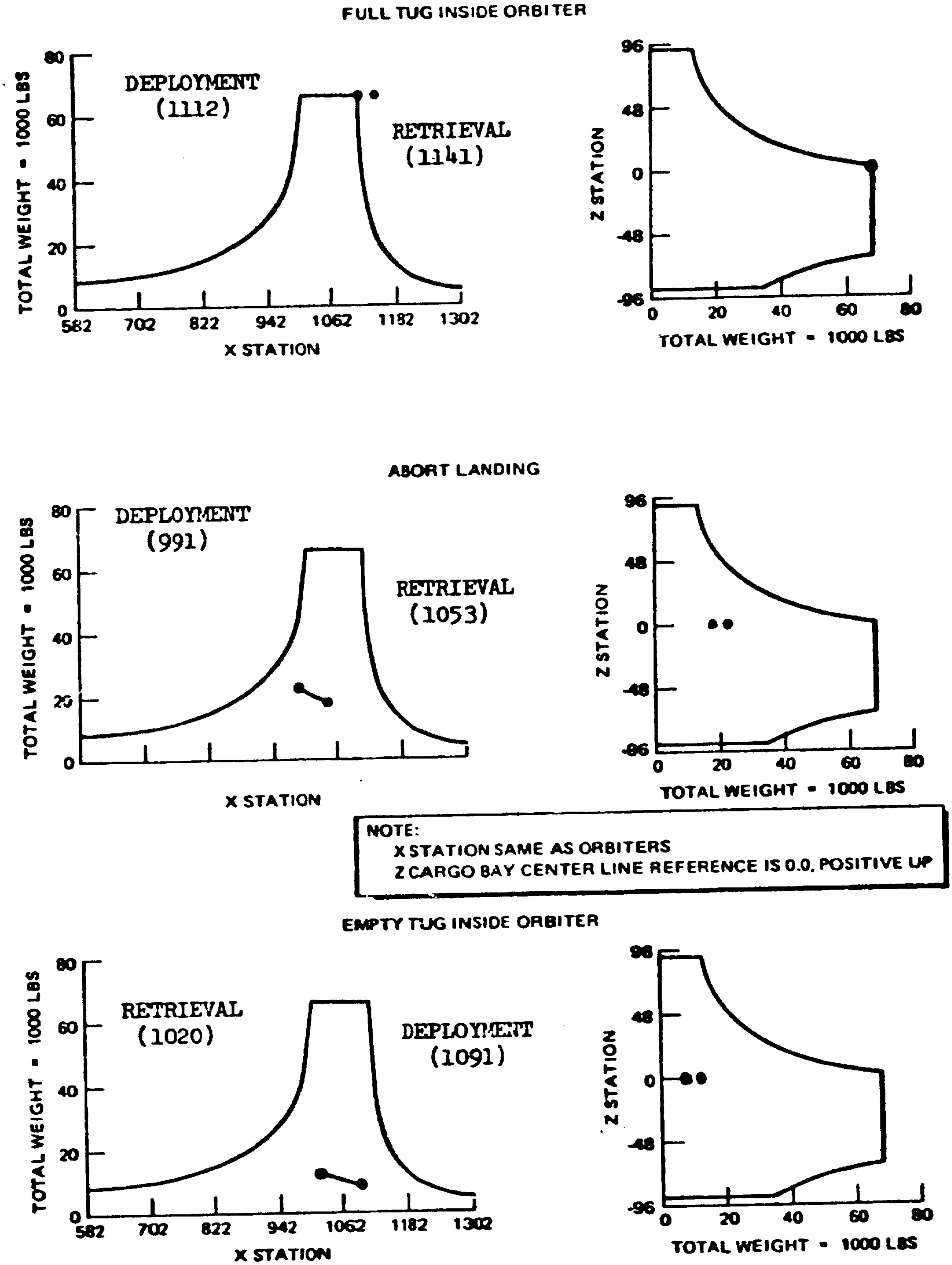

Figure 2-16. Orbiter Center of Gravity Limits – Option 3F

and 6, respectively.

2.10 RELIABILITY SUMMARY — OPTION 3I AND 3F

Two reliability design requirements were used to evolve the Tug configuratio The first was to a-sure a minimum reliability of 0.97 for the overall Tug system; the second was to assure all subsystems met the defined failure tolerance criteria, i.e., they were fail safe as a minimum and fail operational/ fail safe for critical functions. These two requirements are met by the Option 3I and 3F configurations for the single stage Tug and are obtained for the augmented Tug as shown in the following paragraphs. Tables 2-11 and 2-12 summarize for Options 3I and 3F the major subsystem reliabilities and the associated redundancy level necessary to meet the failure tolerance criteria and system reliability requirement.

Its presently predicted Reliability is 0.982. Two of the possible alternates to meet the Option 3I Tug Reliability requirements of 0.97 with a kick-stage are:

1. Make one criterion for kick-stage selection that will have a 0.9847 Reliability for a 26 hour mission.
2. Increase the single stage Tug Reliability to 0.9878 for the same mission time.

Figure 2-17 (Option 3-I) shows that for a mission time of 26 hours, the Tug would have a 0.9850 reliability, hence requiring a Reliability increase of 0.0028. Referring to Table 2-13, it is seen that this would be exceeded by adding a redundant computer/DCU/SCU and also increase the possible mission times to 140 hours as seen on Figure 2-17.

Figure 2-18 (Option 3-F) shows that for augmentation with a kick stage, the Tug Reliability requirement is still met, although the margin by which it exceeds 0.9700 is less than for Option 2. This difference between Options 2 and 3-F results from Option 3-final having twice the number of ACPS fuel tan due to the added usage of the aft thrusters for propellant settling. This ha the effect of slightly decreasing the Option 3 final reliability as shown on Figure 2-18.

Table 2-11

REDUNDANCY SUMMARY - OPTION 3I

Subsystem/Reliability	Redundancy Level
Structures (0.999999)	None - Design per MSFC HDBK 505
Propulsion (0.991404)	
Main Engine	None - Fail safe shut down
Main Engine Support System	Component - Fail safe shut down
ACPS	Component - Fail operational/fail safe for critical functions
Thermal Control	None - Not critical per failure tolerance criteria
Avionics (0.991947)	Component - Except for computer which uses RDP for backup of stability function
Interface Systems (0.999871)	
P/L Separation	None - Fail safe
Tug/OSS Separation	None - Fail safe (Crew EVA action not included)
TOTAL RELIABILITY SINGLE STAGE (0.983221)	

Table 2-12

REDUNDANCY SUMMARY - OPTION 3F

Subsystem/Reliability	Redundancy Level
Structures (0.999999)	None - Design per MSFC HDBK 505
Propulsion (0.986785)	
Main Engine	None - Fail safe shut down. Redundant Feed Shutoff Valves provided in the Support System.
Main Engine Support System	Component - Fail safe shut down
ACPS	Component - Fail operational/fail safe for critical functions
Thermal Control	None - Not critical per failure tolerance criteria
Avionics (0.995677)	Component - Except for the GNC laser radar and TVC battery which are not critical to orbit safety.
Interface Systems (0.999807)	
P/L Separation	None - Fail safe
Tug/OSS Separation	None - Fail safe (Crew EVA action not included)
TOTAL RELIABILITY SINGLE STAGE (0.982268 FOR 144 HOUR MISSION)	

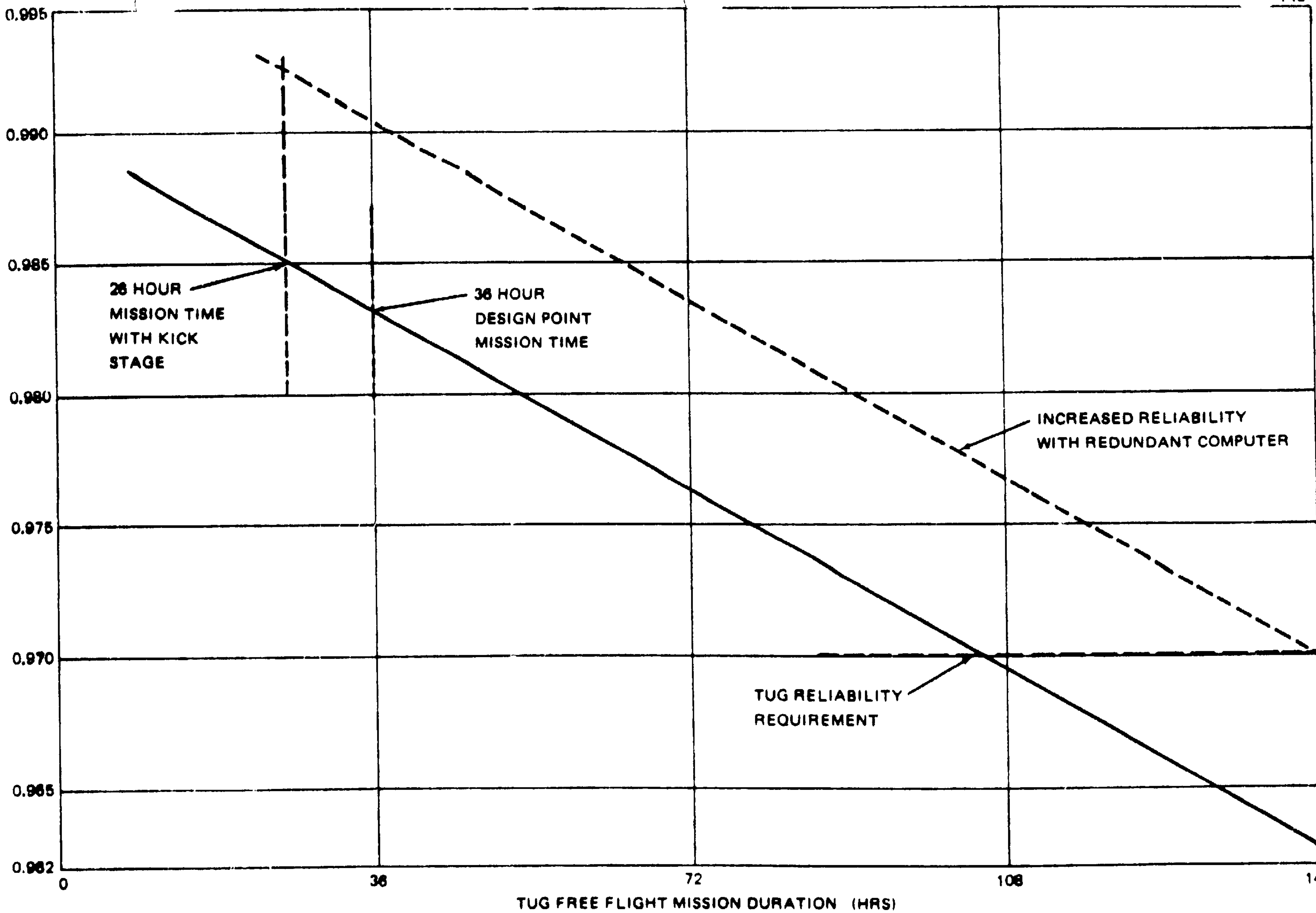

Figure 2-17. Reliability vs Mission Time – Option 31

Table 2-13

TIME/K-FACTOR SUMMARY

Mission Phase	Duration-Hours	K-Facto
Launch and Boost	1/4	15
In Orbiter Bay (Coast)	24	1
Tug Coast	Mission Dependent	1
Tug Engine Burn	1/2	7
Reentry	1/4	7
Non-Operating	Mission Dependent	1/25

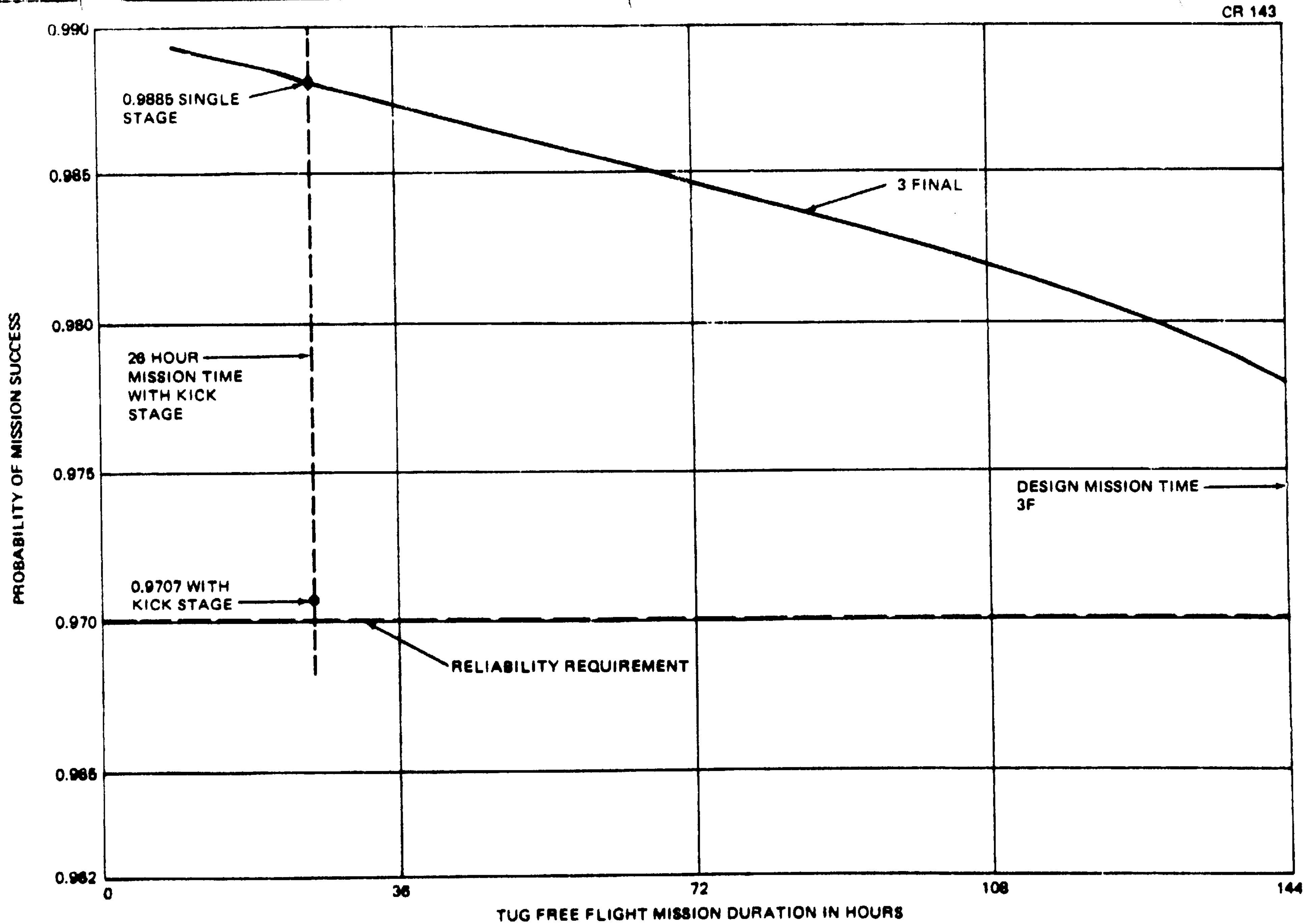

Figure 2-18. Reliability vs Mission Time – Option 3F

The Auxiliary Control Propulsion System and Avionics redundancies provide fa
operational/fail safe for critical functions in these subsystems.

A complete definition of the failure tolerance criteria and the compliance by subsystem is contained in Volume 5, Section 6. Essentially, the criterion is defined so that no single Tug failure may result in a hazard which jeopardiz the flight or ground crews.

The subsystem and system reliability prediction used standard methodology. Th environmental adjustment factors (K-factors) and mission phase durations use are given in Table 2-13. Reliability calculation are based on:

$$R = 1 - \sum_{i=1}^{n} \lambda_i N_i T_i$$

where there are n items in the system, there are N of the ith item, and the failure rate (λ) is adjusted as shown in the detail assessment sheets of Volume 5, Section 6.

Redundancy selection considered the system reliability requirement, weight penalty and cost implications. Redundant items were added sequentially in or of the largest reliability improvement per pound of added weight first to ma tain low RDT&E costs and secondly to achieve the most Reliability improvemen per added pound of weight. Tables 2-14 and 2-15 show the reliability/weight relationships for Options 3I and 3F. Considering the Burner II as representa of a kick stage.

2.11 SYSTEM SAFETY SUMMARY

This Option 3 Tug when designed, produced, and operated under the constraint of the criteria and requirements shown, will from a safety standpoint, provide NASA with a vehicle well within an acceptable risk level for the Space Shuttle Program. The following features should be incorporated.

Table 2-14

OPTION 3I: RELIABILITY/WEIGHT SUMMARY

36 HOUR MISSION; 1 PAYLOAD DEPLOYED; BASELINE R = 0.9339

No. Items in System	No. Redundant	Nomenclature	Total ΔWeight in Lb	ΔIncrease in R per Lb Wgt	Redundant System R
40	20	PWR Distribution	20	0.0004	0.9419
6	3	Inertial Mea Unit	50	0.0003	0.9587
2	1	ACPS Press. Xducer	1	0.0003	0.9590
4	2	ACPS Temp Xducer	1	0.0002	0.9592
2	1	Remote Data Processor	11	0.0002	0.9617
2	1	Star Sensor	16	0.00008	0.9629
10	5	Module Int Unit	135	0.00007	0.9729
2	1	Tape Recorder	20	0.00006	0.9741
2	1	Orbiter Elect Interface	20	0.00006	0.9753
12	6	Comm Comps	45	0.00005	0.9777
2	1	Inst and Software	100	0.00005	0.9827
2	1	Comp/DCU and SCU	26	0.0003	0.9897

Table 2-15

OPTION 3-F: RELIABILITY/WEIGHT SUMMARY

144 HOUR MISSION; ROUND TRIP; BASELINE R = 0.7718

No. Items in System	No. Redundant	Nomenclature	Total Δ Weight in Lb	Δ Increase in R per Lb Wgt	Redundant System R
6	3	Inertial Mea Unit	10	0.0063	0.8348
40	20	Pwr Distribution	10	0.0015	0.8498
6	3	ACPS Press. Xducer	3	0.0012	0.8534
2	1	Computer/DCU (Plus Internally Redundant SCU)	26	0.0010	0.8795
8	4	ACPS Temp Xducer	2	0.0009	0.8813
2	1	Remote Data Processor	11	0.0007	0.8893
2	1	Star Sensor	10	0.00045	0.8938
2	1	Inst and Software	100	0.0003	0.9248
12	6	Module Int Unit Components	160	0.0002	0.9629
2	1	Tape Recorder	20	0.0002	0.9674
12	6	Comm Components	45	0.0002	0.9764
2	1	Fuel Cell	45	0.0001	0.9801
2	1	Orbiter Elect Interface	20	0.00007	0.9823

2.11.1 Design

1. Burst discs and relief valves in the ACPS, Pneumatic supply system, Ambient Helium system and the tank purge system. These systems will vent to the Tug overboard vent system.
2. Incorporation of relief valves on the insulation purge bags.
3. Incorporation of separate shut-off valves for the GHe supply to the purge bags to preclude cross flow of leaked propellants through the system.
4. Identified single point failure of thruster chamber valve either by leakage or inadvertent operation. Valve design selection changed to provide two series valves, one normally closed and the other capable of latching in either the open or closed position.
5. Identified system inhibit and override functions.
6. Incorporate a container for each battery to retain leaked/spilled electrolyte.

.11.2 Production

1. Established leak rate levels of GHe for H_2 system tests.
2. Provided preliminary analyses of refurbishment concepts to assure identification of hazardous functions and to reduce exposure to the hazards; i.e., safing of pressurized systems prior to disassembly, monitoring for toxic vapors, testing pressurized systems at levels acceptable for personnel exposure.
3. Preliminary analyses of the proposed materials and the fabrication methods shows no hazards with which MDAC is not already handling satisfactorily.

2.11.3 Operations

1. Provided preliminary analyses of operational concepts to assure identification of hazardous operations and sequencing those operations to reduce exposure to these hazardous operations; i.e., pressurization of GHe pressure vessels with a 2:1 design ratio to a level not to exceed 4:1 when operational personnel are exposed; restraints in storable propellant loading and detanking, etc.
2. Identified items for crew warning/caution monitoring, hazard potentials at the tilt table interface, and at the Tug/orbiter hard points.

re-entry.

4. Determined toxicity levels for hydrazine and established requirements for monitoring after the monopropellant system is filled.
5. Assisted in analyzing hazards related to abort and post landing recovery.
6. Performed calculations to determine impact of fluids on the orbiter bay. These calculations are shown in Vol 7 paragraphs 5.1 through 5.

2.11.4 Residual Hazards and Rationale for Acceptance 3I

The residual hazards identified to date are corrosion, fire, explosion, press and toxicity. The materials or situations which fit into any of these four ca gories have been itentified and the rationale for acceptance analyzed for eac of the following cases.

Analysis and Rationale for acceptance of each of these hazards is discussed i detail in Volume 7.

2.11.5 Residual Hazards and Rationale for Acceptance 3F

The residual hazards identified to date are corrosion, fire, explosion, press and toxicity. The materials or situations which fit into any of these four ca gories have been identified and the rationale for acceptance analyzed for eac of the following cases.

Analysis and Rationale for acceptance of each of these hazards is discussed i detail in Volume 7.

Table 2-10

OPTION 3I

Source	Location
Corrosion	
Hydrazine	ACPS
Potassium Hydroxide	Batteries
Fire	
Hydrogen	LH_2 Tank and Batteries
Hydrazine	ACPS
Thermal Insulation	Encapsulates Tanks
Wiring Insulation	General
Bonding Resins	General
Explosion	
Hydrogen	LH_2 Tank and Batteries
Hydrazine	ACPS
Pressure	
H_2	Propellant Tanks, Pressurization and Pneumatics Purge System and ACPS
O_2	
GH_e	
GN_2	
Toxicity	
GN_2	Pressurant
GH_2	Propellant
GH_e	Purge
KOH	Batteries
Hydrazine	ACPS

OPTION 3F

Source	Location
	Corrosion
Monomethy/Hydrazine	ACPS
Nitrogen Tetroxide	ACPS
	Fire
Hydrogen	LH_2 Tank Fuel Cells
Monomethy/Hydrazine	ACPS
Thermal Insulation	Encapsulates Tanks
Wiring Insulation	General
Bonding Resins	General
	Explosion
Hydrogen	LH_2 Tank and Batteries
Monomethy/Hydrazine	ACPS
	Pressure
H_2 O_2 GH_e	Propellant Tanks, Pressurization and Pneumatics Purge System and ACPS
	Toxicity
GN_2	Pressurant
GH_2	Propellant
GH_e	Purge
MMH	ACPS
N_2O_4	ACPS

Section 3
PERFORMANCE AND CAPABILITIES

3.1 SYSTEM PERFORMANCE SUMMARY

3.1.1 Mission Performance

The performance capability was computed for each mission in the mission model and for each mission mode—deploy, retrieve, round trip, and expendable. Table 3-1 summarizes the general mission descriptions. The performance results are given in Tables 3-2 and 3-3. A discussion of the derivation and application of these data is presented in Vol. IV, Section 1.1, 1.4, and 1.5.

3.1.2 Performance Envelope

The parameteric performance capabilities (payload vs velocity curves) are presented in Figures 3-1 through 3-6 for 28.5 deg, 55 deg, and 90 deg inclinations, respectively. Additional details of the inputs and applications of these data are given in Vol. IV, Sections 1.1, 1.3, and 1.4. The numbered diamonds indicate the performance requirements for each mission.

3.2 MISSION CAPTURE

Missions for Option 3 commence from ETR in 1980 and from WTR in 1983. The total number of payloads scheduled for deployment by this Option is 387 and for retrieval is 171. Since some deployment missions carry multiple payloads, 371 total missions are required. The configurations are potentially capable of accomplishing all of the missions identified. The availability of the Shuttle for tug flights in 1980 limit Tug flights to 3 and in 1981 limit tug flights to 21. To effectively use this launch rate in 1980 flights were selected NASA flights to aid in the development in a logical manner. In 1981 the 2 smallest payloads were left out since they could most easily be flown on current expendable launch vehicles.

Table 3-1

MISSION DESCRIPTIONS

Mission No.	$H_a \times H_p$ (nmi)	Incl	Remarks
1-8	19323	0	Synchronous orbit - single burn transfer orbit injection
1-8A	19323	0	Synchronous orbit - two burn transfer injection
1-8B	19323	0	Synchronous orbit - two burn transfer injection with 600 fps f multiple payload deployments
9	IAU	Eclip	
10	6900	55°	
10A	6900	55°	Alternate - Shuttle launched into 28.5°
11	16K x 30K	20°	
12	180 x 1800	90°	
13	1K x 20K	90°	
13A	1K x 20K	90°	ETR Alternate - Shuttle launched into 28.5°
13B	1K x 20K	90°	ETR Alternate - Shuttle launched into 55°
14	300 x 3000	90°	
15	700	100°	
16	500	99.2°	
17-8	Interplanetary	ΔV - 13000	

Tal 3-1

MISSION DESCRIPTIONS (Continued)

Mission No.	$H_a \times H_p$ (nmi)	Incl	Remarks
19			16500
20			23000
21-2			24000
23			18400
24			22000
D11	58K	0, 30, 60	
D10	860 x 21K	63.4	Shuttle launch into 63.4° WTR
D10A	860 x 21K	63.4	ETR Alternate - Shuttle launched into 55°
D5	750	99°	
D3	13.6K x 25K	60°	Shuttle launched into 60° WTR
D3A	13.6 x 25K	60°	ETR Alternate - Shuttle launched into 55°
D12	300	104°	
D16	400	98.3°	

a-2

CØNFIGURATIØN ØPT 3I STAGE WT=7470.00 ISP=441.80 DELISP=4.00

@ EMK ~5.5:1

MISSIØN	GRØSS-WT V-ØUT	PL-RØUND V-BACK	PL-DEPLØY	PL-RETRIEVE	PL-EXPENI
		1325 @4.5:1	3531		
1-8	62665.00	1180.76	3172.11	1880.90	15770.11
	13972.00	13920.00			
1-8A	62665.00	1231.27	3307.79	1961.36	15905.79
	13890.00	13920.00			
1-8B	62665.00	868.42	2383.23	1366.29	15413.22
	14190.00	14220.00			
9	62665.00	809.44	2241.96	1266.82	15462.01
	14160.00	14350.00			
10	50665.00	5310.99	10574.20	10670.20	17976.98
	9700.00	9700.00			
10A	62665.00	2767.37	6846.79	4644.70	17858.35
	12760.00	12760.00			
11	62665.00	3228.05	7812.70	5500.94	18421.96
	12450.00	12450.00			
12	32665.00	16144.57	18987.95	107813.19	20303.55
	2285.00	2285.00			
13	32665.00	2440.66	4430.96	5433.60	10522.55
	8400.00	8400.00			
13A	62665.00	1798.80	4677.18	2922.94	16630.40
	13460.00	13460.00			
13B	50665.00	2859.24	6332.44	5213.06	15406.43
	11200.00	11200.00			
14	32665.00	12122.56	15652.73	53751.35	17828.04
	3600.00	3600.00			
15	26665.00	13476.58	15205.26	118538.25	16163.46
	1700.00	1700.00			
16	26665.00	15274.58	16538.70	199841.87	17156.90
	1120.00	1120.00			
17-8	62665.00	2154.20	5518.38	3533.60	17184.18
	13140.00	13250.00			
19	62665.00	.00	.00	.00	11623.93
	16740.00	17210.00			
20	62665.00	.00	.00	.00	4304.11

2_2	62665.00 24600.00	.00 25500.00	.00	.00	3458.35
23	62665.00 18720.00	.00 19550.00	.00	.00	9120.04
24	62665.00 22500.00	.00 23500.00	.00	.00	5215.34
)11	62665.00 13930.00	1200.44 13930.00	3227.25	1911.44	15839.50
)10	48665.00 8500.00	7086.95 8500.00	12957.84	15641.85	19146.04
)10A	50665.00 9800.00	5130.80 9800.00	10288.22	10235.13	17796.97
)5	26665.00 1770.00	13269.42 1770.00	15046.12	112373.37	16046.30
)3	48665.00 11850.00	1576.80 11850.00	3657.12	2771.98	13512.44
)3A	50665.00 11920.00	1855.46 11920.00	4324.84	3249.63	14266.47
)12	26665.00 500.00	17367.61 500.00	17995.17	498015.37	18265.09
)16	26665.00 850.00	16163.48 850.00	17168.87	276020.25	17633.52

CØNFIGURATIØN ØPT 3F STAGE WT=7160.00 ISP=441.80 DELISP=4.0(

EMR=5.5:1

MISSIØN	GRØSS-WT V-ØUT	PL-RØUND V-BACK	PL-DEPLØY	PL-RETRIEVE	PL-EXPI
1-8	62665.00 13972.00	1490.76 13920.00	4004.91	2374.72	16080.|
1-8A	62665.00 13890.00	1627 @ 5.0:1 1541.27 13920.00	4350 4140.60	2455.17	16215.'
1-8B	62665.00 14190.00	1178.42 14220.00	3233.96	1854.01	15723.:
9	62665.00 14160.00	1119.44 14350.00	3100.58	1751.99	15772.(
10	50665.00 9700.00	5620.99 9700.00	11191.41	11293.02	18286.!
10A	62665.00 12760.00	3077.37 12760.00	7613.76	5165.00	18168.:
11	62665.00 12450.00	3538.05 12450.00	8562.98	6029.21	18731.!
12	32665.00 2285.00	16454.57 2285.00	19352.54	109883.37	20613.!
13	32665.00 8400.00	2750.66 8400.00	4993.76	6123.75	10832.!
13A	62665.00 13460.00	2108.80 13460.00	5483.23	3426.67	16940.·
13B	50665.00 11200.00	3169.24 11200.00	7019.00	5778.27	15716.·
14	32665.00 3600.00	12432.56 3600.00	16053.01	55125.88	13138.(
15	26665.00 1700.00	13786.58 1700.00	15555.03	121265.00	16473.·
16	26665.00 1120.00	15584.58 1120.00	16874.35	203897.69	17466.!
17-8	62665.00 13140.00	2464.20 13250.00	6312.50	4042.11	17494.:
19	62665.00 16740.00	.00 17210.00	.00	.00	11933.!
20	62665.00 23550.00	.00 24500.00	.00	.00	4614.

Table 3-3 (Continued)

21-2	62665.00 24600.00	.00 25500.00	.00	.00	3768.35
23	62665.00 18720.00	.00 19550.00	.00	.00	9430.04
24	62665.00 22500.00	.00 23500.00	.00	.00	5525.34
D11	62665.00 13930.00	1510.44 13930.00	4060.65	2405.04	16149.50
D10	48665.00 8500.00	7396.95 8500.00	13524.64	16326.05	19456.04
D10A	50665.00 9800.00	5440.80 9800.00	10909.83	10853.53	18106.97
D5	26665.00 1770.00	13579.42 1770.00	15397.62	114998.62	16356.30
D3	48665.00 11850.00	1886.80 11850.00	4376.11	3316.95	13822.44
D3A	50665.00 11920.00	2165.46 11920.00	5047.41	3792.55	14576.47
D12	26665.00 500.00	17677.61 500.00	18316.37	506904.62	18575.09
D16	26665.00 850.00	16473.48 850.00	17498.16	281314.06	17943.52

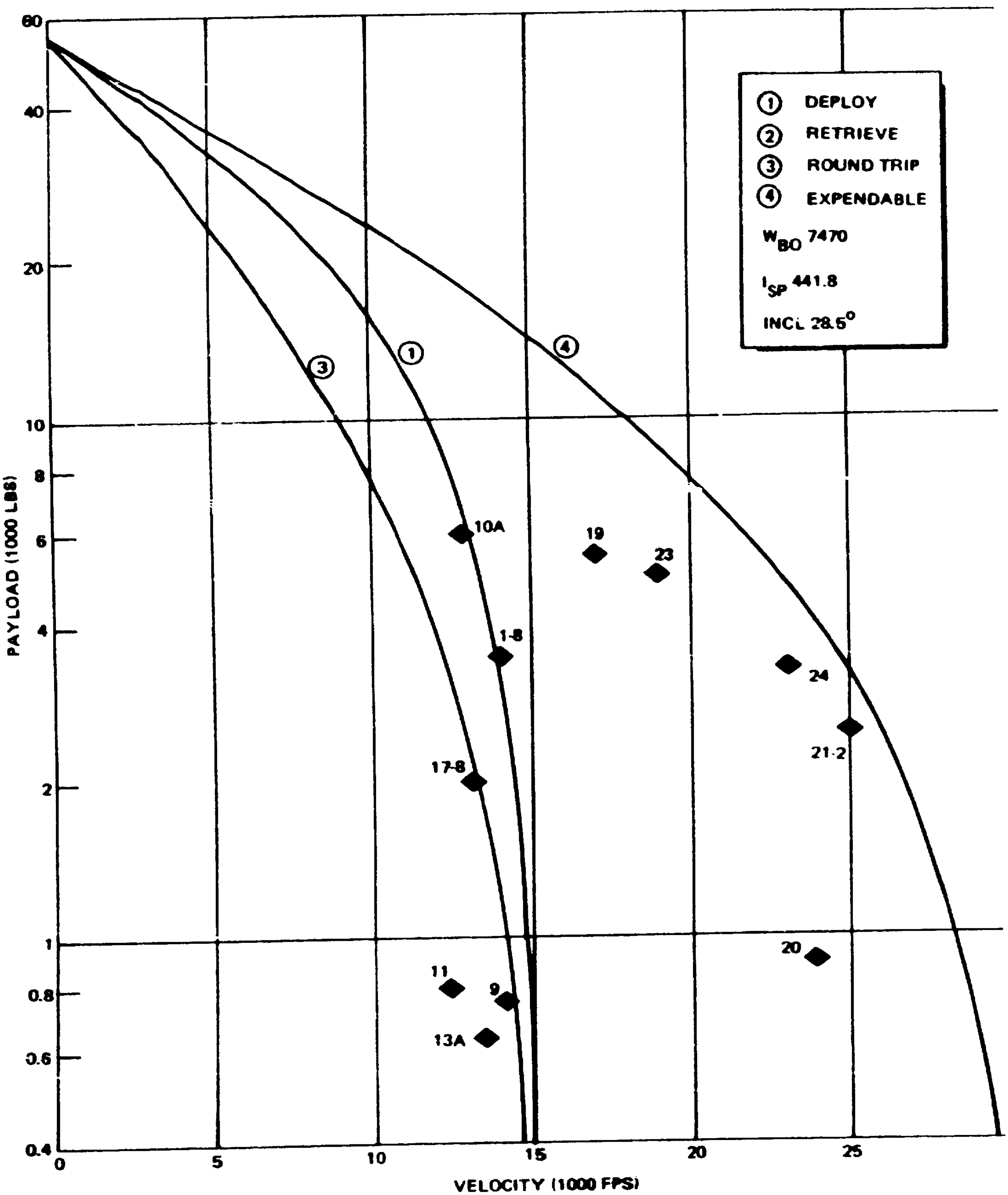

Figure 3-1. Performance Capability Configuration 31

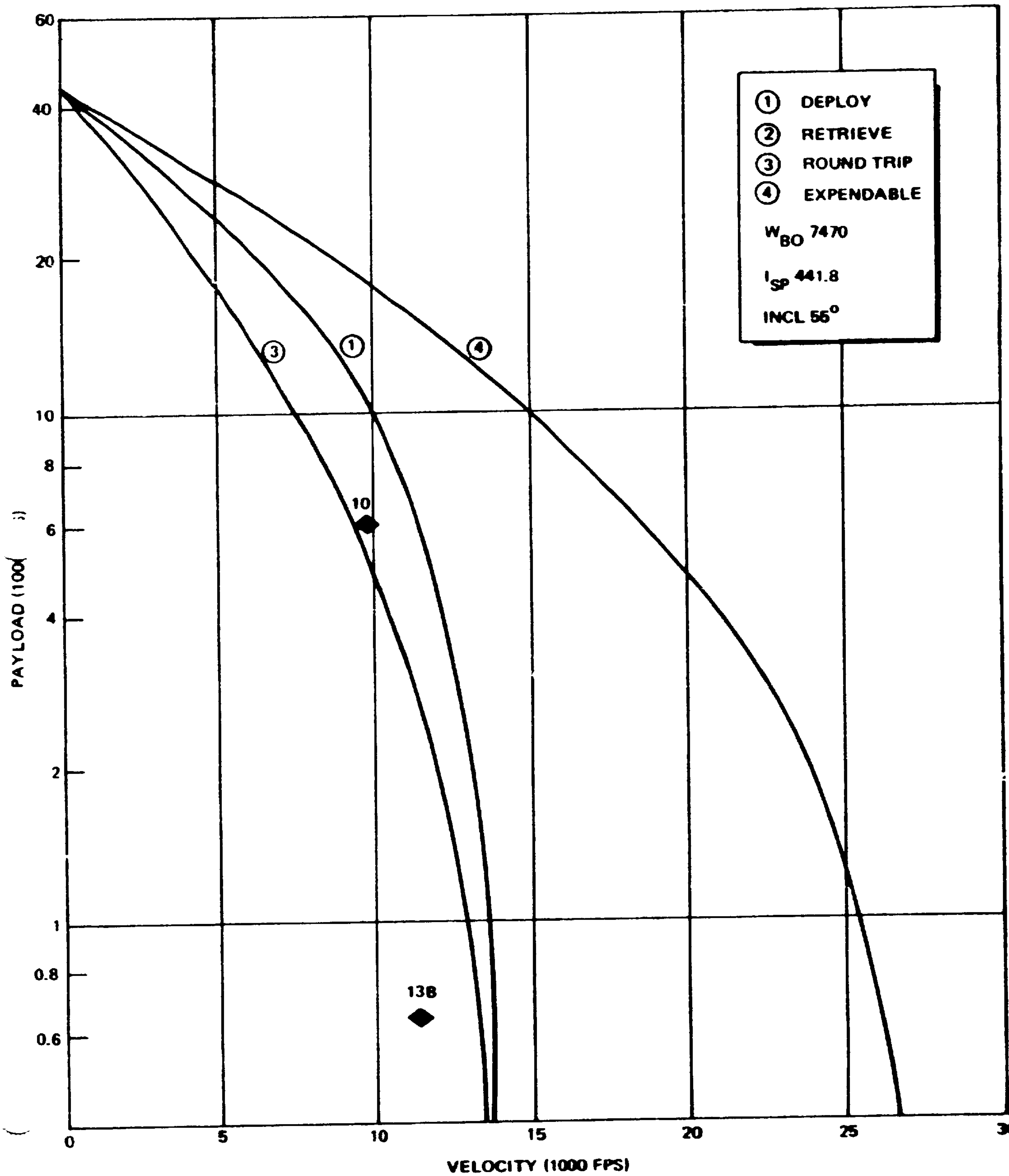

Figure 3-2. Performance Capability Configuration 31

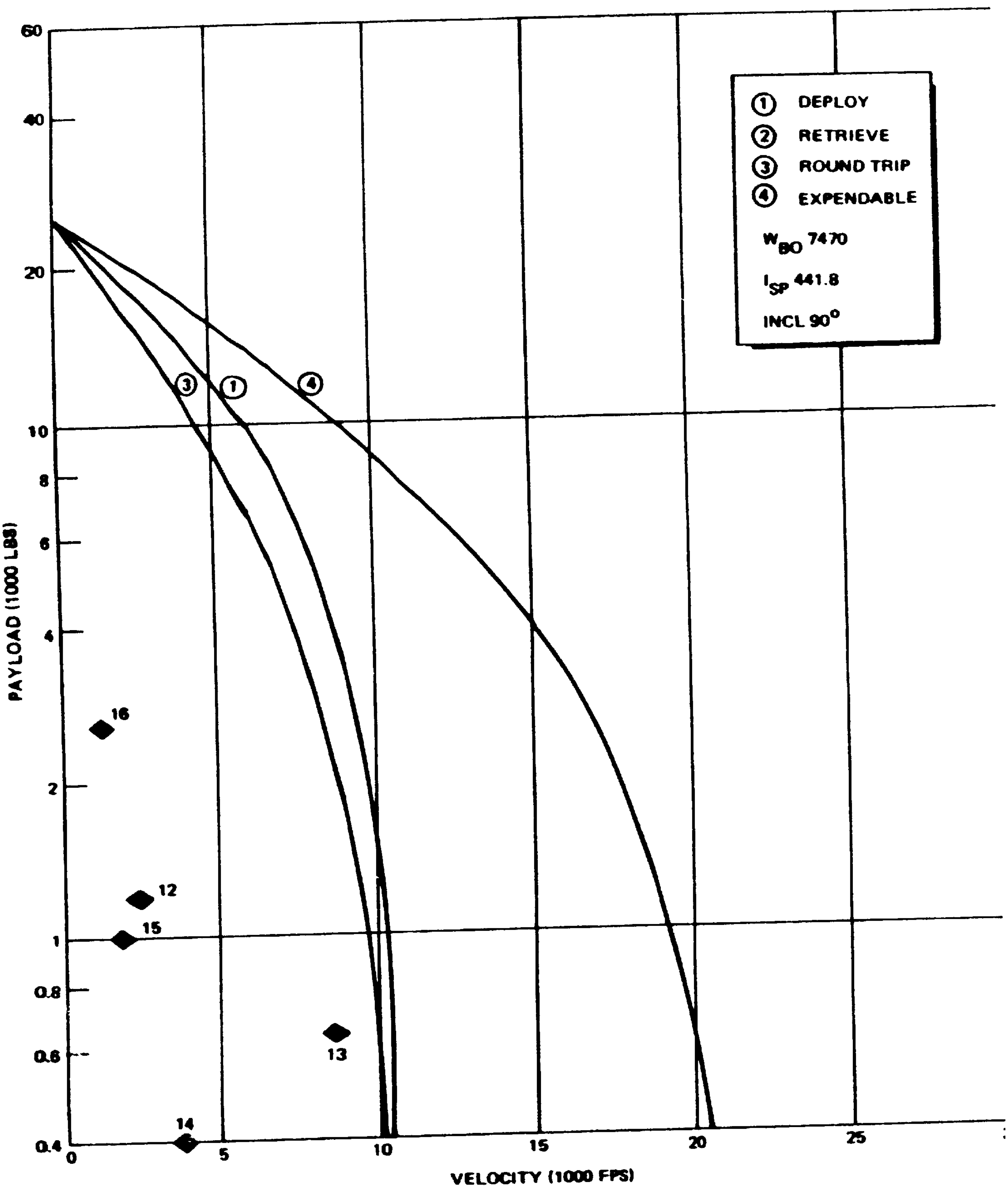

Figure 3-3. Performance Capability Configuration 31

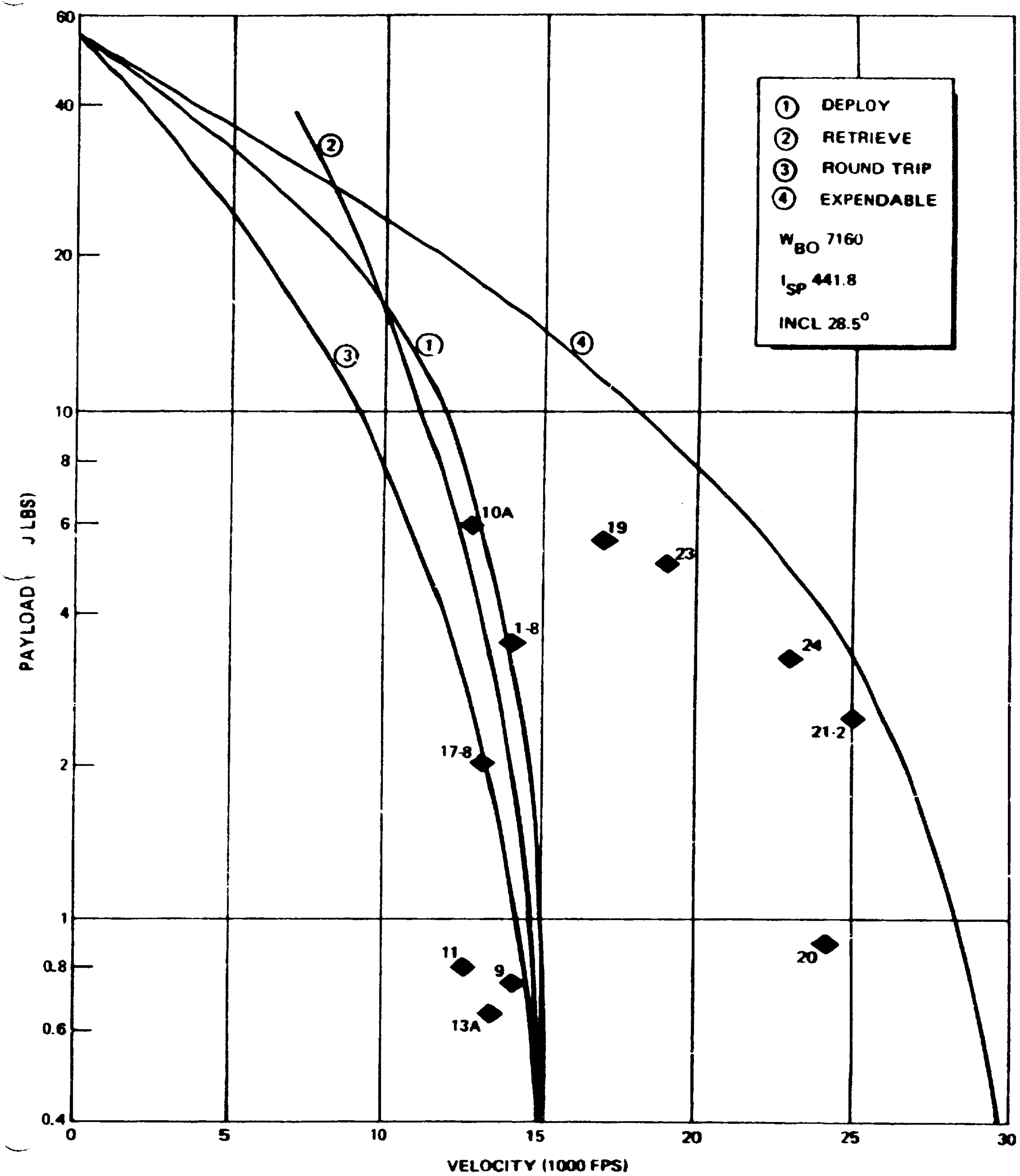

Figure 3-4. Performance Capability Configuration 3F

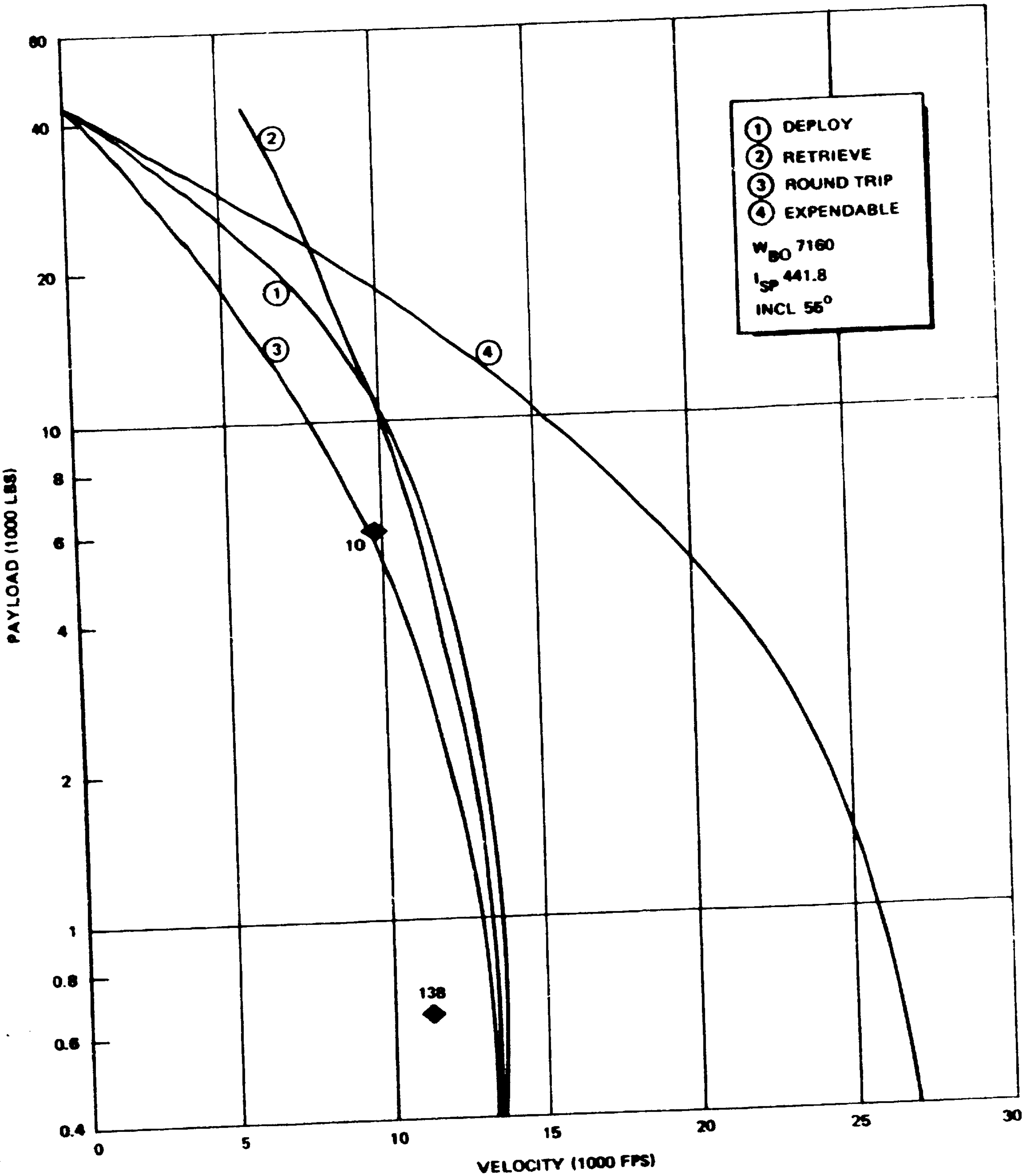

Figure 3-5. Performance Capability Configuration 3F

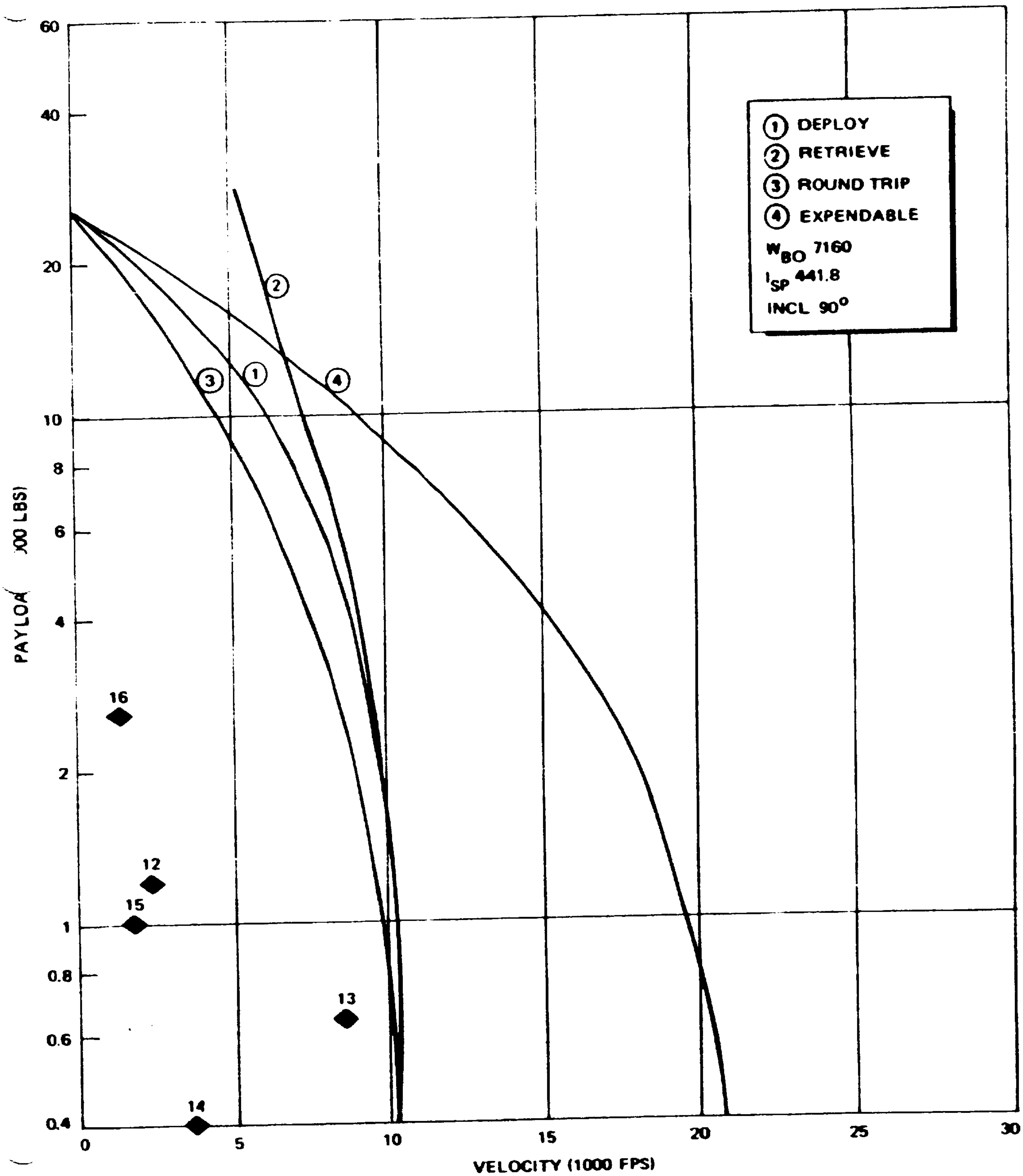

Figure 3-6. Performance Capability Configuration 3F

The flight modes utilized by this Option over its 11 year operational period include the following:

Initial Configuration

1. Basic Tug-reusable (deployment)
2. Basic Tug-expendable (deployment)
3. Basic Tug plus Polaris class auxiliary stage (deployment)
4. Basic Tug-dedicated mode

Final Configuration

1. Basic Tug-reusable (deployment and retrieval)
2. Basic Tug-dedicated mode
3. Basic Tug-reusable multiple mission (multi-deployment/single retrieval)

The scope of the flight operations to accomplish the necessary missions include a total of 370 launches divided as follows:

1. NASA Mission Launches
   a. ETR 179 (82 Initial, 97 final configuration)
   b. WTR 37 (4 Initial, 33 final configuration)
2. DOD Mission Launches
   a. ETR 129 (38 Initial, 91 final configuration)
   b. WTR 21 (6 Initial, 15 final configuration)
3. 4 reflights (1 Initial, 3 final configuration) required to accommodate mission losses due to failures.

The annual launch rate is summarized in the accompanying flight schedules Tables 3-4, 3-5, 3-6, 3-7, and 3-8 for NASA and DOD and for ETR and WTR.

3.3 FLEET SIZE

The fleet size requirements for this program involve the requirements for two different Tug vehicles (the initial configuration with somewhat limited capabilities and the final configuration which incorporates retrieval capability and increased on orbit stay time). Factors which affect the fleet sizing are

Table 3-4

FLIGHT SCHEDULE

TUG CONCEPT OPTION 3

LAUNCH SITE ETR/WTR AGENCY NASA/DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)**		3	21	23	36	44	40	41	40	38	41	41	370
Auxiliary Stage				(2)	(1)	(2)		(3)	(2)				(10)
Drop Tanks													
(Other)	1*												1
Shuttle	1*	3	21	23	36	44	40	41	40	38	41	41	371

( ) Denotes number expended.

Remarks: 33 payloads not accommodated due to Shuttle limits of 3 Tug flights in 1980 and 21 in 1981
*IVU test flight
**Includes reflights due to Tug reliability losses

FLIGHT SCHEDULE

TUG CONCEPT OPTION 3

LAUNCH SITE ETR AGENCY NASA

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)		3	14	12	15	22	22	20	18	15	20	18	179
Auxiliary Stage				(2)		(2)		(3)	(2)				9
Drop Tanks													0
(Other)	1*												1
Shuttle	1*	3	14	12	15	22	22	20	18	15	20	18	180

( ) Denotes Number expended.

Remarks: 13 NASA payloads not accomplished due to Shuttle limit on Tug fligh
*IVU test flight

FLIGHT SCHEDULE

TUG CONCEPT OPTION 3

LAUNCH SITE ETR AGENCY DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)			7	10	13	17	11	12	14	16	12	17	129
Auxiliary Stage					(1)								(1)
Drop Tanks													0
(Other)													0
Shuttle			7	10	13	17	11	12	14	16	12	17	129

( ) Denotes number expended.

marks: 20 DOD payloads not accomplished due to Shuttle limit on Tug flights

TUG CONCEPT OPTION 3

LAUNCH SITE WTR AGENCY NASA

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)					4	4	6	4	6	4	5	4	37
Auxiliary Stage													0
Drop Tanks													0
(Other)													0
Schuttle					4	4	6	4	6	4	5	4	37

( ) Denotes number expended.

TUG CONCEPT OPTION 3

LAUNCH SITE WTR AGENCY DOD

COMPANY MDAC

	79	80	81	82	83	84	85	86	87	88	89	90	Total
Tug (basic)					4	1	2	5	2	2	4	1	21
Auxiliary Stage													0
Drop Tanks													0
(Other)													0
Shuttle					4	1	2	5	2	2	4	1	21

( ) Denotes number expended.

required to perform missions in the last year of operations, the first year and the peak year and (3) the ground turnaround time.

A candidate usage and Tug introduction schedule is presented in the accompanying chart.

At the top of the chart, the number of flights per year is shown and the number of Tug expendable flights. The number of Tugs required were established by first determining the number of Tugs necessary to accomplish the 1990 requirements and working backward from that point to 1984. The maximum number of flights any Tug can perform in a year is established first by summing the Tug ground turnaround time and the mission time which results in the minimum mission turnaround time. In Option 3 the ground turnaround time is as follows:

Configuration	Ground Turnaround Time (Days)	Average Mission Time (Days)	Average Mission Turnaround Time (Days)
Initial	28.0	1.7	29.7
Final	29.0	3.3	32.3

Using this number and assuming that the maximum number of flights that an expended Tug can make in the year that it is expended is 6 (one-half the maximum turnaround in a year), the fleet of 5 for 1990 is established. Working backward from there it can be seen that in 1989 the three expendable requirements and the necessary vehicles used in 1990 make up the inventory requirements. In 1984 the initial Tug flights are limited by its capabilities (it is able to perform only 17 of the 44 flights) thus the final configuration initial year fleet is established to accomplish the remaining flights. The initial Tug fleet size of 4 is established by the 1983 requirement of 36 flights.

The resulting data show that to carry out the operations a total of 12 Tugs is required of which 4 are initial and 8 are final configurations.

vehicles are required (1 initial and 3 final configurations). Thus the total fleet size necessary is 16 of which 2 initial configurations are required at IOC (1980) and 4 final configurations at IOC (1984).

The equal usage schedule is presented in Table 3-9.

EQUAL USAGE SCHEDULE

OPTION 3

	80	81	82	83	84	85	86	87	88	89	90	Total
Number of Flights	3	21	22	36	44	41	41	40	37	41	40	366
Number of Expended Tugs					2		1			3	1	8
Tug ID												
1	2	9	7	10	4							32
2	1	8	9	10	4							32
3		4	2	10	5	7	5					33
4			4	6	4	6	8	5				33
5					9	8	6	4	4	2		33
6					9	8	6	4	4	2		33
7					9	8	6	4	4	2		33
8						4	6	10	2	5	6	33
9							4	10	3	10	6	33
10								3	10	10	10	33
11									10	5	9	24
12										5	9	14
Reflights/ Losses												

Section 4
OPERATIONS

4.1 FLIGHT OPERATIONS

The work breakdown structure for the Tug Study divides the flight operations into four areas or blocks, namely: Mission Planning, Flight Control, Flight Evaluation, and Flight Support Software. The methodology for deriving the manpower requirements for each of these is presented in Volume 6.

Option 3 is a phased program consisting of two distinct configurations. The initial configuration is operational for four years before the final configuration is introduced and overlaps the final configuration operational period by 4 years for NASA Tugs and 3 years for DOD Tugs. The final configuration has a seven year operational life. The initial configuration has a level IV autonomy, a 3 day mission duration and no rendezvous, docking or spin-up capability. The final configuration has a level III autonomy, a 6 day mission duration and has rendezvous, docking and spin-up capabilities. The appropriate factors including proportional values for the years during the overlap of the two configurations, the number of flights and the mission times were input into the computer program and the resulting manloads were obtained. These are presented in Tables 4-1 and 4-2 and in Figures 4-1 and 4-2.

4.2 GROUND AND LAUNCH OPERATIONS

The results of the ground and launch operations analysis include the detailed definition of all ground and launch operations activities, equipment, manpower and schedules at both the Eastern Test Range (KSC) and Western Test Range (VAFB) which are required to support both NASA and DOD Tug missions.

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Table 4-1

OPTION

TOTAL PROGRAM COSTS

NUMBER OF FLIGHTS =217.0

AUTONOMY LEVEL = 3.0

NASA MISSION

LAUNCH FROM WTR = 37.0

LAUNCH FROM ETR =180.0

FLIGHT OPERATIONS RECURRING COSTS (NASA ONLY)

		MANHOURS	COMPUTER HOURS	COSTS
MISSION PLANNING	=	3673 7.4	3388.9	9044096.4
~~FLIGHT CONTROL~~	~~=~~	~~819241.0~~	~~13000.4~~	~~21350978.5~~
FLIGHT EVALUATION	=	386313.0	4869.5	9631028.2
FLIGHT SOFTWARE	=	159466.0	2362.0	4891308.0
~~UNUSED MANHOURS~~	~~=~~	~~166735.1~~	~~0.0~~	~~3334722.7~~
TOTAL OPS. HOURS	=	1304667.7	23619.8	
TOTAL OPS. COSTS	=	35880027.2	9046388.9	44926411.1

~~OPERATIONS PER/FLT COSTS = 2 7034.2~~

FLIGHT OPERATIONS NON-RECURRING COSTS (TOTAL PROGRAM FOR BOTH DOD

		MANHOURS	COMPUTER HOURS	COSTS
~~MISSION PLANNING~~	~~=~~	~~478764.6~~	~~2008.0~~	~~11543527.2~~
FLIGHT CONTROL	=	52263.9	0.0	1175938.2
FLIGHT EVALUATION	=	0.0	0.0	0.0
FLIGHT SOFTWARE	=	178005.2	3122.3	5200963.6
TOTAL DDT E HOURS	=	709133.7	5130.3	
TOTAL DDT E COSTS	=	15955509.0	1964904.9	17920429.0

Table 4-2

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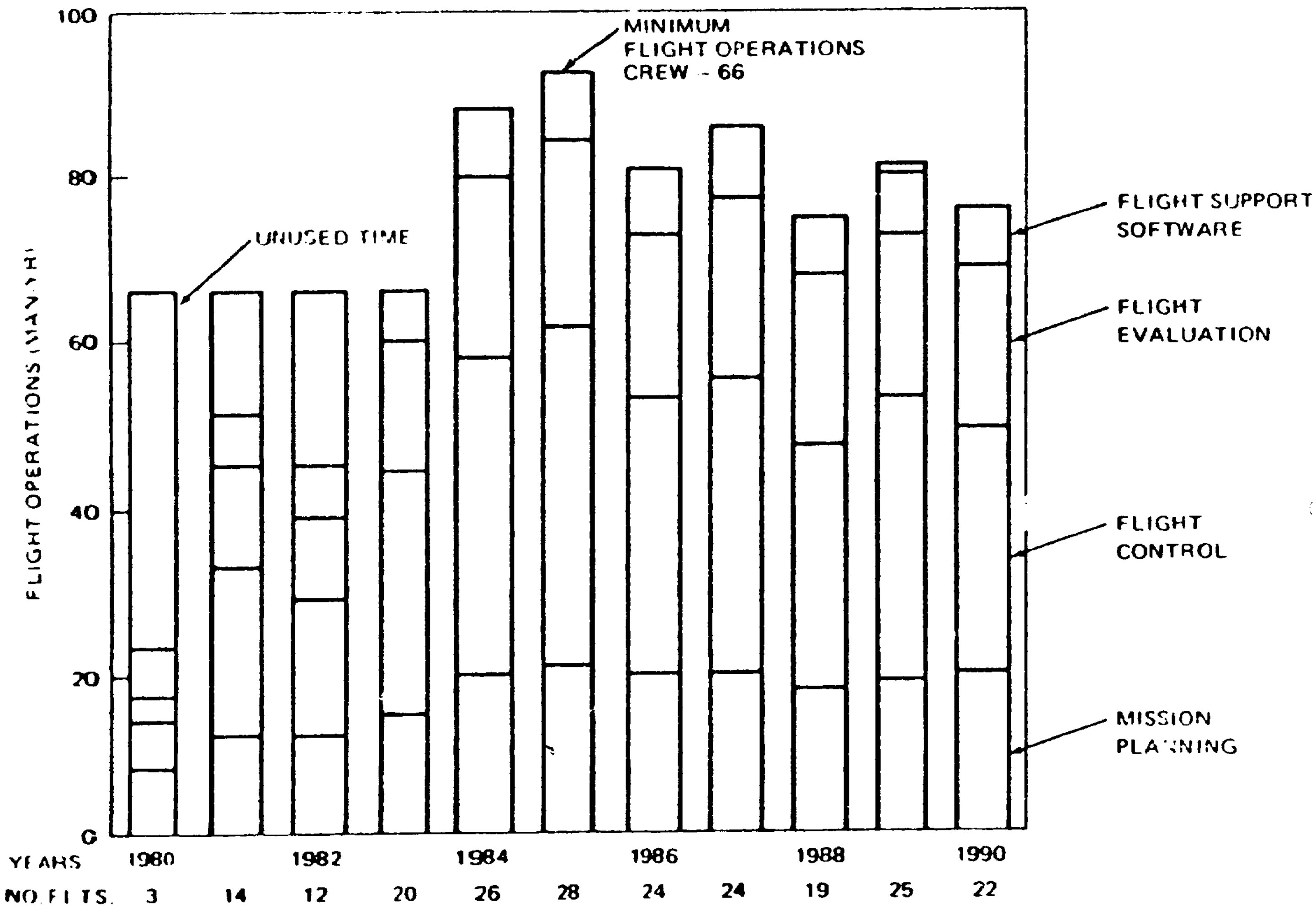
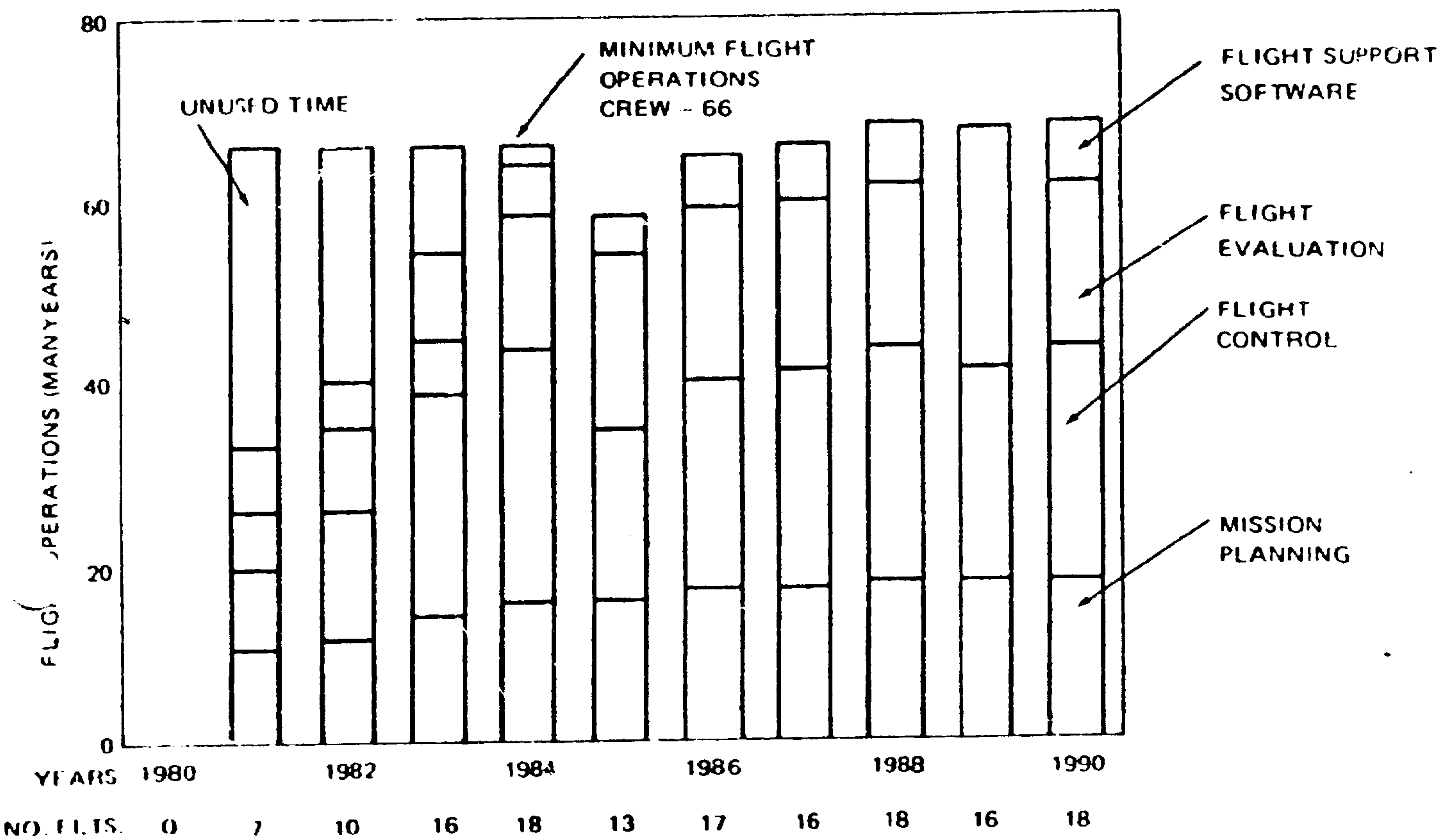
... ON	=	3		
...TAL PROGRAM COSTS				
...MBER OF FLIGHTS	=	149,		
...TONOMY LEVEL	=	3,0		
...D MISSION				
...UNCH FROM WTR	=	21,0		
...UNCH FROM ETR	=	128,0		
...IGHT OPERATIONS RECURRING COSTS (DOD ONLY)				
		MANHOURS	COMPUTER HOURS	COSTS
...SSION PLANNING	=	318[illegible]94,0	2707,8	7399735,0
...IGHT CONTROL	=	596596,2	8923,6	15351655,4
...[illegible]T EVALUATION	=	327177,8	3409,2	7848924,6
...IGHT SOFTWARE	=	124197,1	1671,3	3745026,9
...USED MANHOURS	=	148182,6	0,0	2963651,4
...TAL OPS, HOURS	=	1241777,8	16712,8	
...TAL OPS, COSTS	=	27944344,0	6400998,0	34345341,9
...ERATIONS PER/FLT COSTS	=	230505,7		
...GHT OPERATIONS NON-RECURRING COSTS (TOTAL PROGRAM FOR BOTH DOD & NAS...				
		MANHOURS	COMPUTER HOURS	COSTS
...SION PLANNING	=	478264,6	2004,0	11543527,2
...GHT CONTROL	=	52263.9	0,0	1175938.2
...GHT EVALUATION	=	0,0	0,0	0,0
...[illegible] SOFTWARE	=	178005.2	3122.3	5200963.6
...AL DDT E HOURS	=	709133.7	5130.3	
...AL DDT E COSTS	=	15955509.0	1964904.9	17920429.0



OPTION THREE (NASA MISSION)

TOTAL MANYEARS	=	843
MISSION PLANNING	=	186
FLIGHT CONTROL	-	313
FLIGHT EVALUATION	-	187
FLIGHT SUPPORT SOFTWARE	=	77
UNUSED TIME	-	80

TOTAL FLIGHTS	-	217
WTR FLIGHTS	=	37
ETR FLIGHTS	=	180



OPTION THREE (DOD MISSION)
FLIGHT OPERATIONS MANPOWER REQUIRED

TOTAL MANYEARS	=	656
MISSION PLANNING	=	153
FLIGHT CONTROL	=	216
FLIGHT EVALUATION	=	157
FLIGHT SUPPORT SOFTWARE	=	60
UNUSED TIME	=	70

TOTAL FLIGHTS	-	149
WTR FLIGHTS	=	21
ETR FLIGHTS	=	128

The overall study/program objectives which related to the ground and launch operations are:

- Low cost, development and operational, shall be a prime objective i the attainment of the Space Tug capability.
- The Tug shall be fully reuable capable of operating throughout the program duration with refurbishment/replacement of life limited components as required.
- The mission success reliability goal for the Tug shall be 0.97 minimum for all mission phases.
- The Space Tug will be designed to be returned to earth in the Shutt and be reused; reusability with minimized maintenance/ground turn-around cost is a design objective.
- The Tug shall achieve reasonable turn-around times and effective mission cost by reducing as much as possible, maintenance and inspection of systems, resulting in minimum subsystem replacements between flights.

Consideration of these objectives resulted in the identification of eleven major analyses which were evaluated to determine the required ground and launch operations resources. These analyses and the summary of results is shown below.

	Analysis	Results 3I	3F	3 Composite
1.	Ground Operations Cost	ETR \$39.19M WTR \$25.6M	\$57.84M \$ 7.93M	\$97.03M \$33.53M
2.	Manning Reqmts	Peak Yr Req ETR 168 WTR 119	ETR 245 WTR 90	ETR 290 WTR 181
3.	Active Tug Fleet Size	ETR 3 Max 1 Min WTR 1	ETR 4 Max 2 Min WTR 1	ETR 4 Max 1 Min WTR 1
4.	Total Program Fleet Size	ETR 2 WTR 2	ETR 6 WTR 2	ETR 8 WTR 4

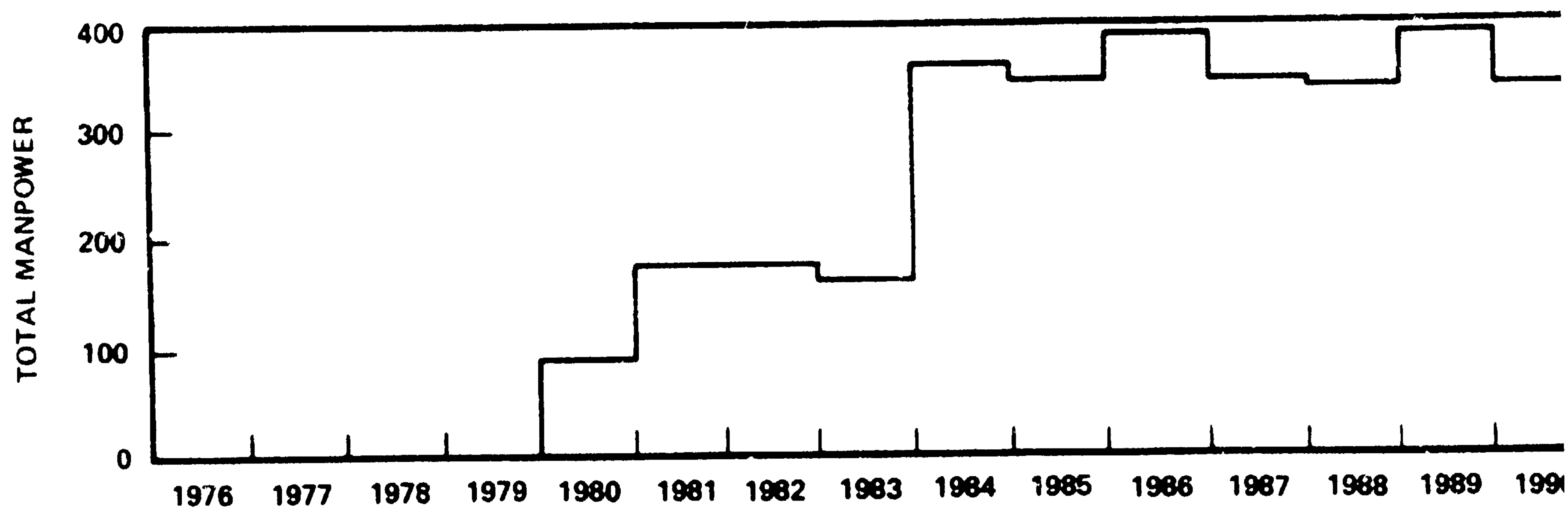
Analysis	Results 3I	3F	3 Composite
5. 2 Yr IOC Delay	243 Man Yr Reduction	No effect	243 Man Yr. Reduction
6. Shuttle Restrained Operations	Land to Land + 21 Hr Liftoff-144 Hr to Liftoff	Land to Land + 21 Hr Liftoff-144 Hr to Liftoff	Land to Land + 21 Hr Liftoff-144 Hr to Liftoff
7. Ground Turn-around Time	ETR 306 NASA 319 DOD WTR 309 NASA 309 DOD	ETR 328 NASA 341 DOD WTR 324 NASA 324 DOD	ETR 328 NASA 341 DOD WTR 324 NASA 324 DOD
8. Task Description Development	55 Functional Tasks Defined	58 Functional Tasks Defined	58 Functional Tasks Defined
9. Facility Reqmts Description	Requires New P/L Process Fac at ETR & WTR	Requires New P/L Process Fac at ETR & WTR	Requires New P/L Process Fac at ETR & WTR
10. GSE Description	77 Types GSE Req'd See Table 4-3	83 Types GSE Req'd See Table 4-4	83 Types GSE Req'd See Table 4-4
11. Maint/Refurb/CO Impact on Turnaround	Maint/Refurb/CO Requires ≈ 75 Hr	Maint/Refurb/CO Requires ≈ 75 Hr	Maint/Refurb/CO Requires ≈ 75 Hr

Additional manpower and cost data is shown in Figure 4-3.

Appropriate data associated with each of these analyses and detail discussions are presented in Volume 6.

4.3 REFURBISHMENT SUMMARY

The MDAC Space Tug Refurbishment (R) Concept minimizes R requirements while ..intaining a satisfactory degree of launch on time probability together with the required level of subsystem reliability to assure mission success. It is patterned after the commercial airlines "On Condition Maintenance" philosophy which monitors subsystem health and thus precludes unwarranted maintenance and



GROUND OPERATIONS	OPT 3 I	F
● TURNAROUND TIME	309 HRS	
● AVERAGE MANPOWER	147	
● TOTAL COST	TBD	
● LAUNCH SITE COSTS	TBD	
● MAINTENANCE COSTS	TBD	
● OPS COST PER FLIGHT	TBD	

properly. Subsystem health is monitored by a combination of the following techniques:

- Operational instrumentation data consisting of subsystem performance measurements which are telemetered during flight via ground link.
- When the Tug is out of range of a ground tracking station, these data are recorded onboard for later transmission.
- Post Flight/Receiving Inspection.
- Automated subsystem checkout (ground) of those performance characteristics not readily adaptable to inflight monitoring.
- Use of onboard checkout capability for fault detection and isolation.

The Maintenance/Refurbishment (M/R) technical approach/methodology is not sensitive to individual Tug configurations; however, the cost of an M/R cycle and depot maintenance will vary with different configurations. These variations have been expressed in the M/R inputs to the cost model for each configuration in terms of Manhours/(M/R) cycle, equivalent units of production hardware for operational spares and depot maintenance cost as a percentage of average subsystem hardware cost.

The maintainability analyses have evaluated unscheduled maintenance as this affects maintenance and refurbishment schedules, and has predicted unscheduled maintenance manhours and spares requirements. These are provided in Volume 6. In addition, the analysis has produced predictions of risk of launch with an anomaly in the Tug and risk of pad loadout as a result of anomalies discovered subsequent to Tug/Shuttle mating.

The predictions are based upon a systematic analysis of the equipment operated (data management, fueling, communications, etc.) and length of operation according to the top level functional flow diagram, and system timelines. The total risk is apportioned to risk of pad loadout or to launch unreliability on the basis of individual subsystem verification capability incorporated in the design of the Tug and Tug/Shuttle combined integrated systems test. The results of the predictions are shown in a comparisons format in Figures 4-4 and 4-5.

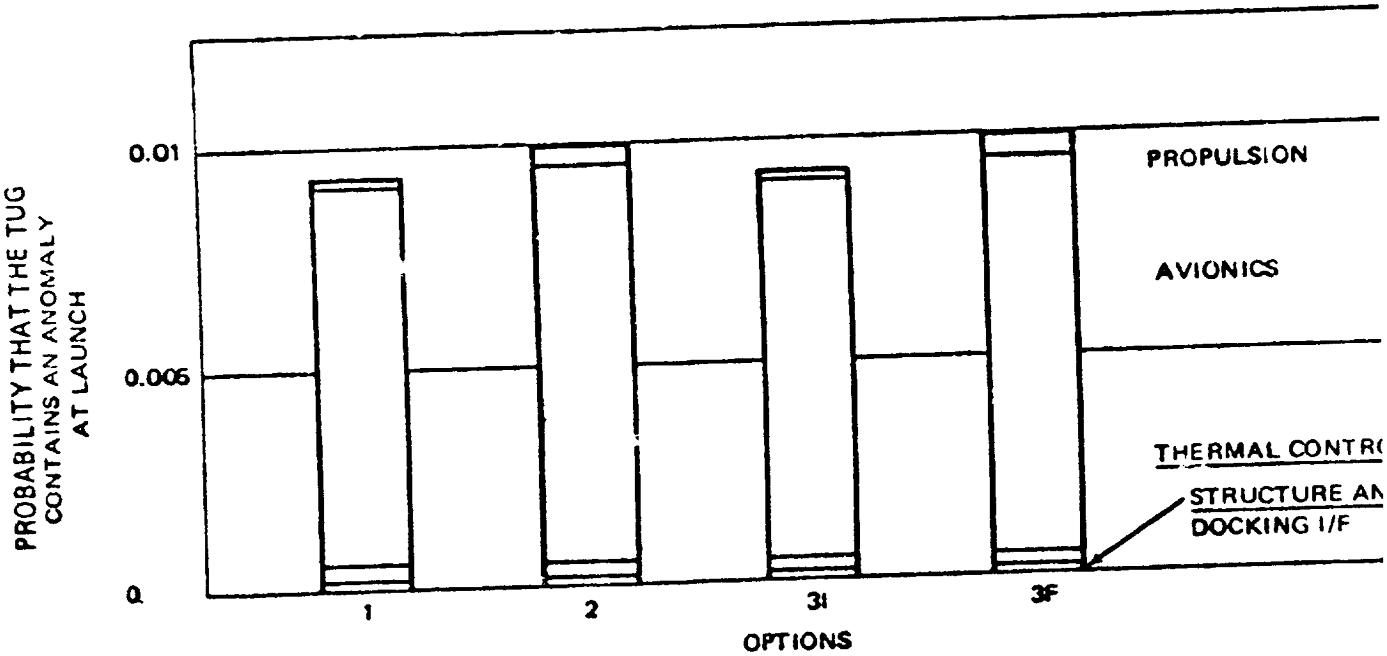


Figure 4-4. . Comparisons of Tug Unreliability at Launch

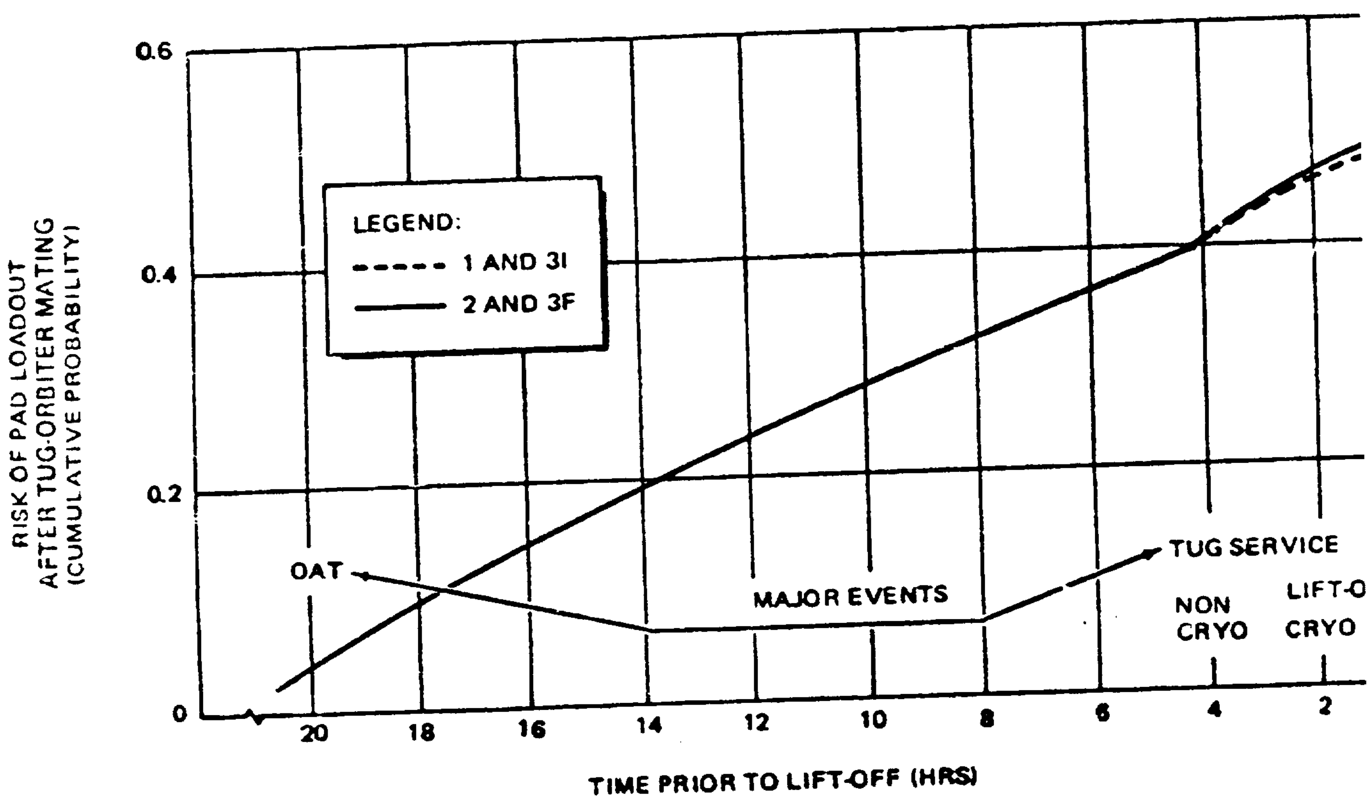


Figure 4-5. Risk of Tug Loadout Due to Prelaunch Anomaly

The results of the GSE task include the detailed definition of the GSE, quantities, price, development schedule, and GSE ast each location for factory, Eastern Test Range (KSC) and Western Test Range (VABF) which are required to support both NASA and DOD Tug missions. It also includes a definition of equipment that is Government Furnished Equipment (GFE) which is available from the Saturn and Delta program that is usable for Tug.

Option 3 initial features:

A. GSE is sized for fleet sizes of five vehicles for cradles, covers, and transporters.

B. Guidance and Navigation checkout equipment GFE from Delta program.

C. Battery checkout GFE from Saturn program.

D. Factory GSE is shipped to VAFB to become launch checkout equipment. for one pad. Feasible since schedule delivery of 13 vehicles allows enought time to accomplish this.

E. Provide only one pad of GSE at VAFB since launch rates are low from WTR and one set of hardware can support program launch rate from WTR.

F. Utilizes maximum GFE from Saturn program where possible to support KSC.

Option 3 final features:

A. GSE is sized for a fleet size of nine vehicles for cradles, covers and transporters.

B. Features are the same as Option 2 except two pads of GSE and provided at WTR and factory set is available for depot maintenance or future production. In Options 1, 2 and 3 initial the factory set of hardware has been deployed to VAFB as the launch checkout equipment. In option 3 you attain low DDT&E during the initial phase and still have GSE developed during the final configuration to support any configuration checkout and testing turnaround rate. The factory set can be utilized for modification and development of future changes or be moved to the launch site to enable faster turnaround at either KSC or WTR as the situation warrants the higher launch rates.

4.5 LOGISTICS SUMMARY

The MDAC Space Tug Logistics Concept incorporates the Transportation and Handling, Training, Inventory Control and Warehousing functions and Spare

The primary mode of transportation between MDAC and KSC/WTR will be by "G type aircraft when delivering new Tugs or when switching operational Tugs between KSC and WTR. Movement of Tug hardware (other than a complete Tug will be accomplished via appropriate land and air modes as dictated by specific program requirements. The selection of preservation methods, pa aging levels, and protective handling is based on analysis of natural and induced environments to which the hardware will be subjected during its l cycle.

4.5.1 Training

The training concept for the Tug Program is based on the premise that tra will be required for all ground personnel (customer and contractor) and t personnel assigned to the Tug Program will already be skilled in their re tive specialities; therefore, training requirements will be limited to th adaptation of their respective skills to Tug hardware and ground operatic

There will be no requirement for simulators and dedicated training equipm Test and flight hardware, augmented by audio/visual aids will be used. N special training facilities requirements are planned.

4.5.2 Inventory Control and Warehousing

The material control function includes the receiving, shipping, issue, re inventroy control and storage of spares, repair parts and special test eq ment (Contractor Furnished Equipment [CFE] and Government Furnished Equip [GFE]) located at either the MDAC manufacturing facility of at the KSC/W launch sites. Variations in dollar value of the logistics inventory have expressed in the Maintenance and Refurbishment inputs to the cost model.

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE Un Availa
			Factory	ETR	WTR	
104	Air Carry Environmental Kit — VPG	1		1		
105	Air Carry Environmental Kit — VPG	1		1		1
106	Air Carry Roller Transfer Kit — VPG	2				2
107	Air Carry Tie Down Kit — VPG	2		1	1	
108	Air Carry Tie Down Kit — VPG	1		1		
110	Alignment Kit	3		2	1	
111	APS Breakout Control Box	2	1	1	1	
112	APS Loading Accessories Kit	2	1	1	1	
113	APS Servicer	2		1	1	
115	Battery Handling Kit	2		1	1	
117	Checkout Accessories Kit	9	1	4	4	
118	Checkout Cable Kit	10	1	5	4	
119	Communication System Test Set	3	1	1	1	
120	Component Protective Covers	13	1	8	4	
121	COMSEC Equipment	2		1	1	2

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR, Use GSE from Factory Description	Total Units Required	Location Used Factory	 ETR	 WTR	GFE I Avai.
122	Cover — Spacecraft	5		4	1	
123	Cover — Tug	5		4	1	
124	Cradles	5		4	1	
125	Cryogenic Propellant Loading Complexes	3		2	1	
126	Cryogenic Tank Trucks	2		1	1	
127*	Data Management System T/S (DMST/S)	7	1	4	2	
128	Telemetry Ground Station	2		1	1	
129	Digital Events Recorder	3	1	1	1	
130	Engine Actuator Fixture	3	1	1	1	
131	Engine Alignment Kit	3	1	1	1	
132	Engine Handling Kit	3	1	1	1	
133	Engine Position Calibration Fixture	3	1	1	1	
134	Equipment Van	6	1	3	2	
135	FM Transmitter Component Test Set					

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE U Avail
			Factory	ETR	WTR	
136	Frequency Calibration Unit Rack Assembly					
137	Fuel Cell Checkout Kit					
139	Gas Sampling Equipment	6		3	3	
140	Handling Equipment	10	2	5	3	
141	Horizon Sensor Tester					
142	Guidance and Navigation Test Set	3	1	1	1	[illegible]
143	Guidance and Navigation System Checkout Kit	3	1	1	1	[illegible]
144	Laser Radar Checkout and Analysis Kit					
145	Launch Countdown Console	3		2	1	[illegible]
147	LH_2-He Heat Exchanger	3		2	1	
148*	Signal Conditioning Unit	7	1	4	2	
149	Orbiter Simulator	3	1	1	1	
150	Payload Adapter Handling Kit	3		2	1	
151	PCM/FM Telemetry Component Test Set					

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE U Avail
			Factory	ETR	WTR	
152	Personnel Protection Equipment	8		4	4	
153	Pneumatic Console ACPS Portable Test Set	3	1	1	1	
155*	Power System T/S (PSTS)	7	1	4	2	
157	Printed Circuit Card Component Test Set	1	1			
159	Propellant Utilization Component Test Set	3	1	1	1	
160	Propulsion Component Repair Kit	2		1	1	
161	Propulsion Pneumatic Console (Checkout)	5	1	2	2	3
162	Pneumatic Skid Launch	3		2	1	2
163*	Propellant or Pneumatic Control Console	7	1	4	2	4
164	Battery Checkout Kit	2		1	1	2
168	Spacecraft Simulator	3	1	1	1	
169	Space Tug Simulator	3	1	1	1	
172	Stage Transport Preparation GN_2 Purge Unit	2		1	1	1
173	Stage Weight and Balance Kit	3	1	1	1	

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE Ur Avail
			Factory	ETR	WTR	
174	Star Tracker Simulator	3	1	1	1	
175	Static Desiccant Kit	8	2	4	2	
176	Subsystem Monitoring Consoles	9		6	3	6
177	Tape Recorder Component Test Set					
178	Television System Checkout Kit					
180	Environment Conditioning Unit	4	1	2	1	
181	Tilt Table Handling Kit	4	1	2	1	
182	Tractor — Transporter	5	1	2	2	5
183	Transporter	5	1	3	2	
184	Tug Support Kit (Vertical)	2		1	1	
185*	Umbilical System	7	1	4	2	
189	Voice and Timing System	2		1	1	1
190	Wide Band Magnetic Tape Recorder	5		3	2	3
191	Workstand — Kit	12	1	6	5	

Table 4-3

PROGRAM OPTION 3I

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE Uni Availat
			Factory	ETR	WTR	
192	Security Vehicle	6		3	3	6
301	Simulation Flight Test Computer Programs	3	1	1	1	
302	Ground Checkout Computer Programs	3	1	1	1	
304	Ground Checkout Tug Processing Facility Computer Program	3	1	1	1	
305	Ground Support Self-Check Computer Program	3	1	1	1	
306	Launch Countdown Computer Programs	2		1	1	
307	Support Software Computer Programs	3	1	1	1	
308	AEDC Interface Cable Kit	1				
309	Tug Test Cell Holding Fixture	1				
310	AEDC Interface Junction Box	1				
311	Test Software Computer Program	1				
312	Mission Control Tug Subsystem Software	2				
313	DOD Mission Control Status and Monitoring Stations (Totally GFE)	7				7
314	NASA Mission Control Status Monitoring Stations (Totally GFE)	7				7

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY

Identifier Number	Ground Rules; Install One Pad at WTR; Use GSE from Factory Description	Total Units Required	Location Used			GFE U: Avail:
			Factory	ETR	WTR	
104	Air Carry Environmental Kit — VPG	1		1		
105	Air Carry Environmental Kit — VPG	1		1		1
106	Air Carry Roller Transfer Kit — VPG	2		1	1	2
107	Air Carry Tie Down Kit — VPG	2		1	1	
108	Air Carry Tie Down Kit — VPG	1		1		
110	Alignment Kit	3	1	2	1	
111	APS Breakout Control Box	3[(1)]	1	1	1	
112	APS Loading Accessories Kit	3[(1)]	1	1	1	
113	APS Servicer	4[(1)]		2	2	
115	Battery Handling Kit	2		1	1	
117	Checkout Accessories Kit	9	1	4	4	
118	Checkout Cable Kit	11	1	5	5	
119	Communication System Test Set	3	1	1	1	
120	Component Protective Covers	9		7	2	

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GFE from Factory Description	Total Units Required	Location Used			GFE Avai
			Factory	ETR	WTR	
121	COMSEC Equipment	2		1	1	
122	Cover — Spacecraft	9		6	3	
123	Cover — Tug	9		6	3	
124	Cradles	9		6	3	
125	Cryogenic Propellant Loading Complex	3		2	1	
126	Cryogenic Tank Trucks	2		1	1	
127	Data Management System T/S (DMST/S)	8	1	4	3	
128	Telemetry Ground Station	2		1	1	
129	Digital Events Recorder	3	1	1	1	
130	Engine Actuator Fixture	3	1	1	1	
131	Engine Alignment Kit	3	1	1	1	
132	Engine Handling Kit	3	1	1	1	
133	Engine Position Calibration Fixture	3	1	1	1	

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GFE from Factory Description	Total Units Required	Location Used			GFE Uni Availat
			Factory	ETR	WTR	
135	FM Transmitter Component Test Set	1	1			
136	Frequency Calibration Unit Rack Assembly	1	1			
137	Fuel Cell Checkout Kit	3	1	1	1	
139	Gas Sampling Equipment	6		3	3	
140	Handling Equipment	10	1	5	4	
141	Horizon Sensor Tester					
142	Guidance and Navigation Test Set	3 (2)	1	1	1	
143	Guidance and Navigation System Checkout Kit	3 (2)	1	1	1	
144	Laser Radar Checkout and Analysis Kit	3	1	1	1	
145	Launch Countdown Console	4		2	2	2
147	LH_2-He Heat Exchanger	5	1	2	2	
148	Signal Conditioning Unit	8 (1)	1	4	3	
149	Orbiter Simulator	3 (1)	1	1	1	
150	Payload Adapter Handling Kit	3		2	1	

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GFE from Factory Description	Total Units Required	Location Used			GFE Avai
			Factory	ETR	WTR	
151	PCM/FM Telemetry Component Test Set					
152	Personnel Protection Equipment	8		4	4	
153	Pneumatic Console ACPS Portable Test Set	3	1	1	1	
155	Power System T/S (PSTS)	8	1	4	3	
157	Printed Circuit Card Component Test Set	1	1			
159	Propellant Utilization Component Test Set	3	1	1	1	
160	Propulsion Component Repair Kit	2		1	1	
161	Propulsion Pneumatic Console (Checkout)	5	1	2	2	
162	Pneumatic Skid Launch	4		2	2	
163	Propellant or Pneumatic Control Console	9	1	4	4	
164	Battery Checkout Kit	2		1	1	
168	Spacecraft Simulator	3(1)	1	1	1	
169	Space Tug Simulator	3(1)	1	1	1	

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GFE from Factory Description	Total Units Required	Location Used			GFE Avai
			Factory	ETR	WTR	
173	Stage Weigh and Balance Kit	3 (1)	1	1	1	
174	Star Tracker Simulator	3	1	1	1	
175	Static Desiccant Kit	8	2	4	2	
176	Subsystem Monitoring Consoles	12		6	6	
177	Tape Recorder Component Test Set	1	1			
178	Television System Checkout Kit					
180	Environment Conditioning Unit	5	1	2	2	
181	Tilt Table Handling Kit	4	1	2	1	
182	Tractor — Transporter	4	1	2	2	
183	Transporter	7	1	4	2	
184	Tug Support Kit (Vertical)	2		1	1	
185	Umbilical System	9	1	4	4	
189	Voice and Timing System	2		1	1	
190	Wide Band Magnetic Tape Recorder	5		3	2	

Table 4-4

PROGRAM OPTION 3F

GROUND SUPPORT EQUIPMENT SUMMARY (Continued)

Identifier Number	Ground Rules; Install One Pad at WTR; Use GFE from Factory Description	Total Units Required	Location Used			GFE U Avail
			Factory	ETR	WTR	
191	Workstand — Kit	12	1	6	5	
192	Security Vehicle	6		3	3	
301	Simulation Flight Test Computer Programs	3	1	1	1	
302	Ground Checkout Computer Programs	3	1	1	1	
304	Ground Checkout Tug Processing Facility Computer Prog	3	1	1	1	
305	Ground Support Self-Check Computer Prog	3	1	1	1	
306	Launch Countdown Computer Programs	3	1	1	1	
307	Support Software Computer Programs	3	1	1	1	
308	AEDC Interface Cable Kit	1				
309	Tug Test Cell Holding Fixture	1				
310	AEDC Interface Junction Box	1				
311	Test Software Computer Program	1				
312	Mission Control Tug Subsystem Software	1				
313	DOD Mission Control Status and Monitoring Stations (Totally GFE)	7				
314	NASA Mission Control Status Monitoring Stations (Totally GFE)	7				

4.5.3 Spares

The maintainability analyses have addressed unscheduled maintenance in terms of spares requirements. This applies risk of failure analysis methods to prediction of spares requirements and maintenance manhours. All predictions were made by the same methods, thus assuring that the data presents the proper range of relative performance for purposes of preferential evaluation and ranking with regard to unscheduled maintenance.

Spare parts costs estemates were introduced into the cost model in terms of initial spares and depot maintenance, measured in terms of equivalent units of production subsystem hardware costs. The initial spares are required to repair any failure present in a returning Tug for the first five flights. The estimates for subsystems assumed at least one of each replaceable item plus several additional parts for those items having a high failure risk and a long flow time for depot overhaul. The comparison of costs for the separate subsystems are determined. The cost comparison and method of calculation is hown in Section 6.11.4.1 of Volume 6-Operations.

Section 5
PROGRAMMATICS AND COST

5.1 VEHICLE MANUFACTURING SUMMARY

The vehicle manufacturing plan of the initial configuration phased to final configuration space Tugs contains the Space Tug manufacturing plan, includir peak rate charts, Manufacturing Flow Plans, tooling required to manufacture the Space Tug per the prescribed rate and the facilities that will be requi to accomplish the task. Also included in Volume 8 are the problem areas, special processes required, summary analysis and manufacturing philosophy engendered into the manufacturing plan. The breakdowns of Option 3I and 3F are shown in Figure 5-1 and 5-2.

5.1.1 Plan/Flow/Time

The manufacturing plan flow/time elements used for the manufacture of the S Tug are based on the following key factors:

- Low Production requirements
- Low DDT&E costs with ability to grow
- Low Production Manufacturing Costs
- Low Early Year Funding
- Low Manufacturing Rate Requirement
- Test Article Requirements Support
- Utilization of existing Capital Equipment, GSE, and facilities
- High Reliability and Reusable requirements of the Space Tug.
- Phased manufacturing capability – initial configuration to final configuration

The above noted key factors were considered and incorporated into the manuf turing plan with the principal motivating factor being the high reliability and reusability requirement.

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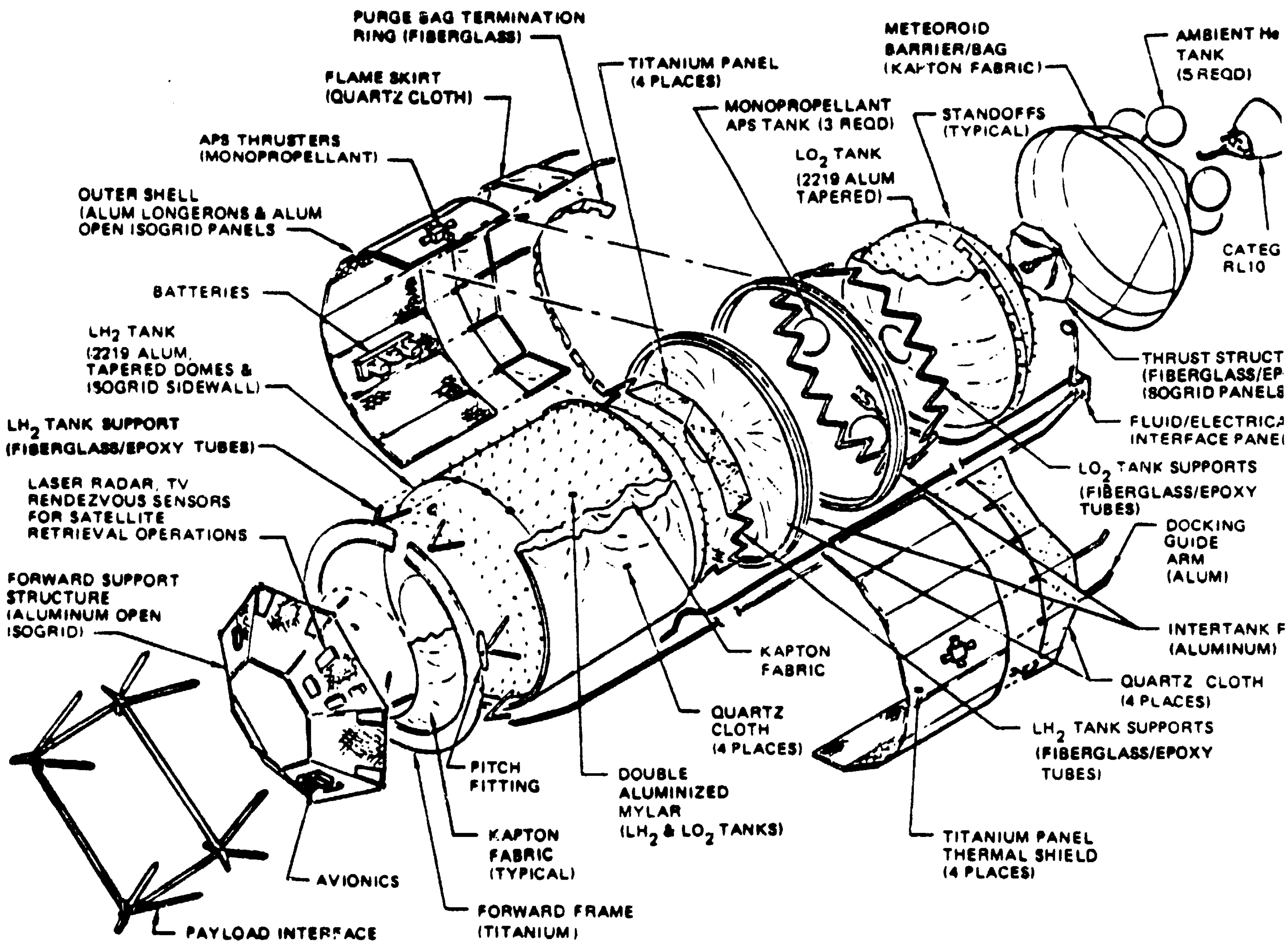


PURGE BAG TERMINATION RING (FIBERGLASS)
FLAME SKIRT (QUARTZ CLOTH)
APS THRUSTERS (MONOPROPELLANT)
OUTER SHELL (ALUM LONGERONS & ALUM OPEN ISOGRID PANELS
BATTERIES
LH_2 TANK (2219 ALUM, TAPERED DOMES & ISOGRID SIDEWALL)
LH_2 TANK SUPPORT (FIBERGLASS/EPOXY TUBES)
LASER RADAR, TV RENDEZVOUS SENSORS FOR SATELLITE RETRIEVAL OPERATIONS
FORWARD SUPPORT STRUCTURE (ALUMINUM OPEN ISOGRID)
AVIONICS
PAYLOAD INTERFACE
FORWARD FRAME (TITANIUM)
KAPTON FABRIC (TYPICAL)
PITCH FITTING
DOUBLE ALUMINIZED MYLAR (LH_2 & LO_2 TANKS)
QUARTZ CLOTH (4 PLACES)
KAPTON FABRIC
TITANIUM PANEL THERMAL SHIELD (4 PLACES)
LH_2 TANK SUPPORTS (FIBERGLASS/EPOXY TUBES)
QUARTZ CLOTH (4 PLACES)
INTERTANK F (ALUMINUM)
DOCKING GUIDE ARM (ALUM)
LO_2 TANK SUPPORTS (FIBERGLASS/EPOXY TUBES)
FLUID/ELECTRICA INTERFACE PANEI
THRUST STRUCT (FIBERGLASS/EP ISOGRID PANELS
CATEG RL10
AMBIENT He TANK (5 REQD)
METEOROID BARRIER/BAG (KAPTON FABRIC)
STANDOFFS (TYPICAL)
LO_2 TANK (2219 ALUM TAPERED)
MONOPROPELLANT APS TANK (3 REQD)
TITANIUM PANEL (4 PLACES)

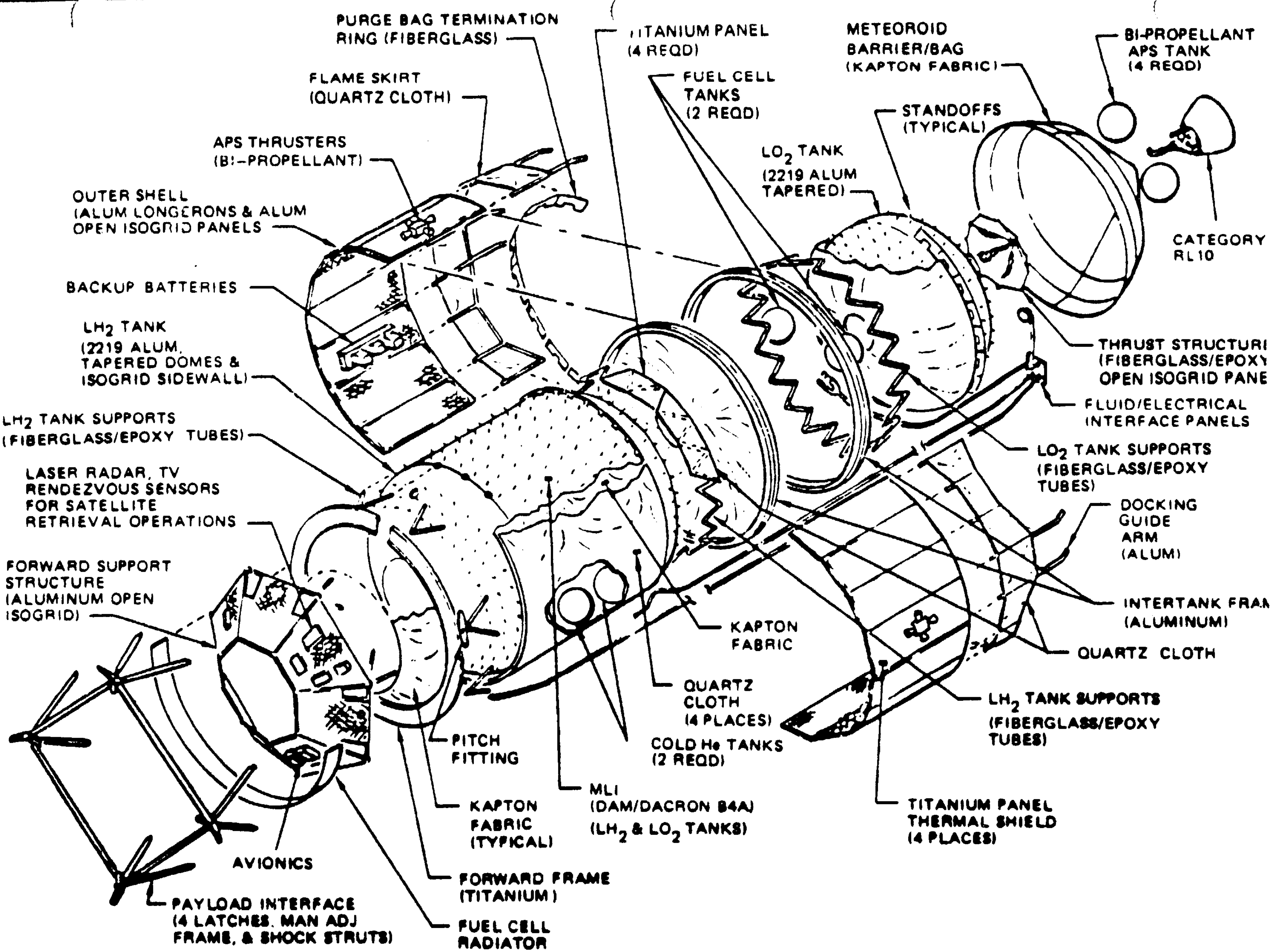


Figure 5-2. Space Tug Configuration – Option 3 Final

This section has been divided into two parts to separate the manufacturing requirements for major test articles from those needed for the production o flight articles. No dedicated flight test articles are planned for this pr gram. Schedule requirements for the major test articles are presented in Volume 8, Section 1.2. Wherever practical or feasible from a schedule stan point, manufactured test components will be fabricated during tool proofing provide lower program cost, reduce Planning effort, provide a greater lead and reduce Tooling setup times for test components.

The following test articles will be produced:

- Structural Test articles
- Propulsion Test Vehicle (PTV)
- Integrated Avionics Test Unit (IATU)
- Flight Control Simulation
- Flight Support Equipment

5.1.3 Manufacturing Schedule and Flow

The manufacturing schedule is based on the Production Schedule, shown in Volume 8, Section 1.3, which is the basis also for the manufacturing flow c lead time set-back charts, and first tool usage requirements.

The manufacturing flow schedules shown in Figures 5-3 and 5-4 begin with Er ing design effort at ATP, and define the sequence of activities by Procurer Planning, Tooling and Manufacturing through detail fabrication, subassembly assembly, integration and installation, through final checkout and preparat shipment. Major inspection points such as proof and leak check are also sh this chart.

The Peak Rate Tree Chart presented in Figure 5-5 shows both detailed manufa steps and the units in flow at peak production rate.

Additional detailed manufacturing sequence flow charts are contained in the facturing Plan which is discussed in detail in Volume 8.

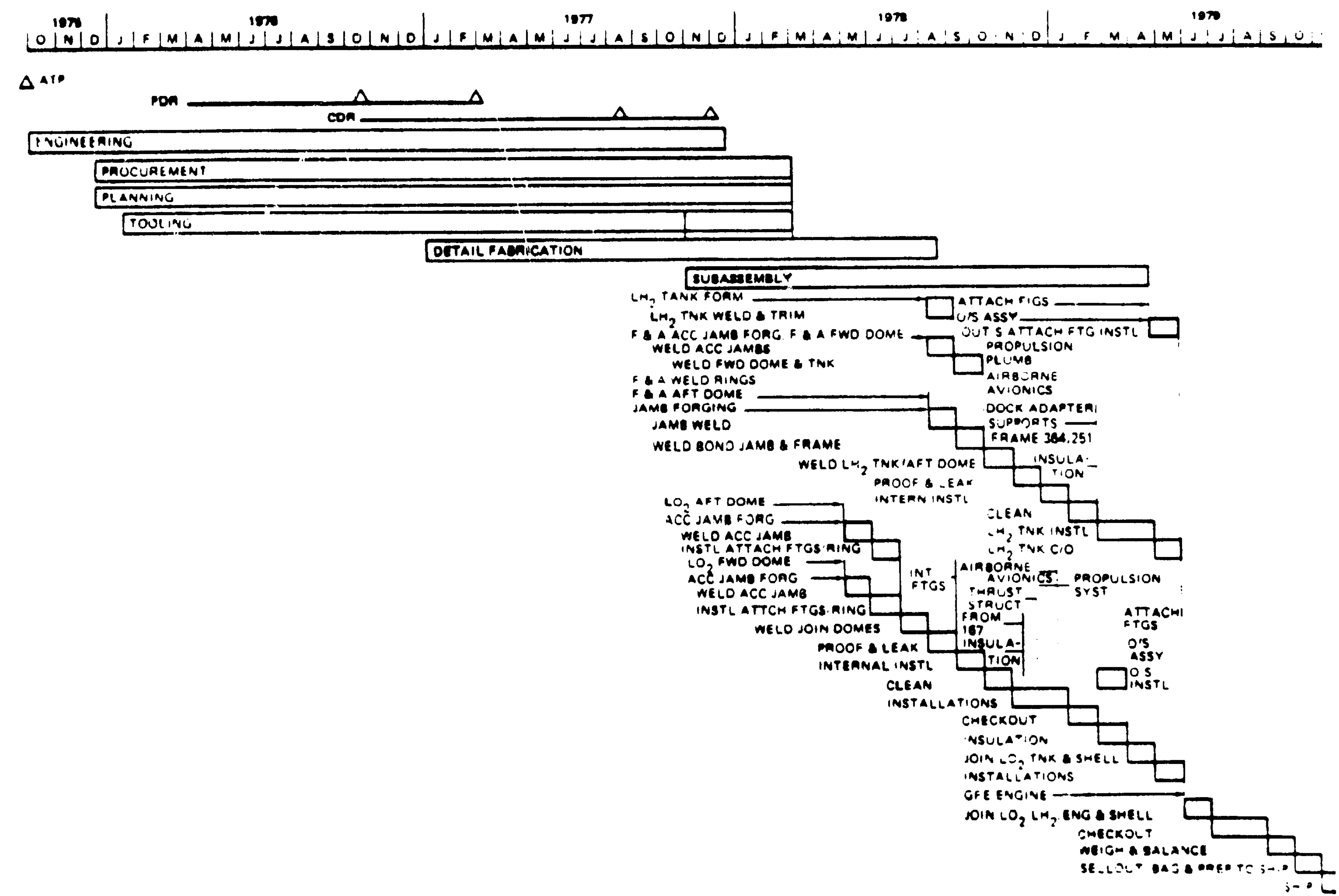
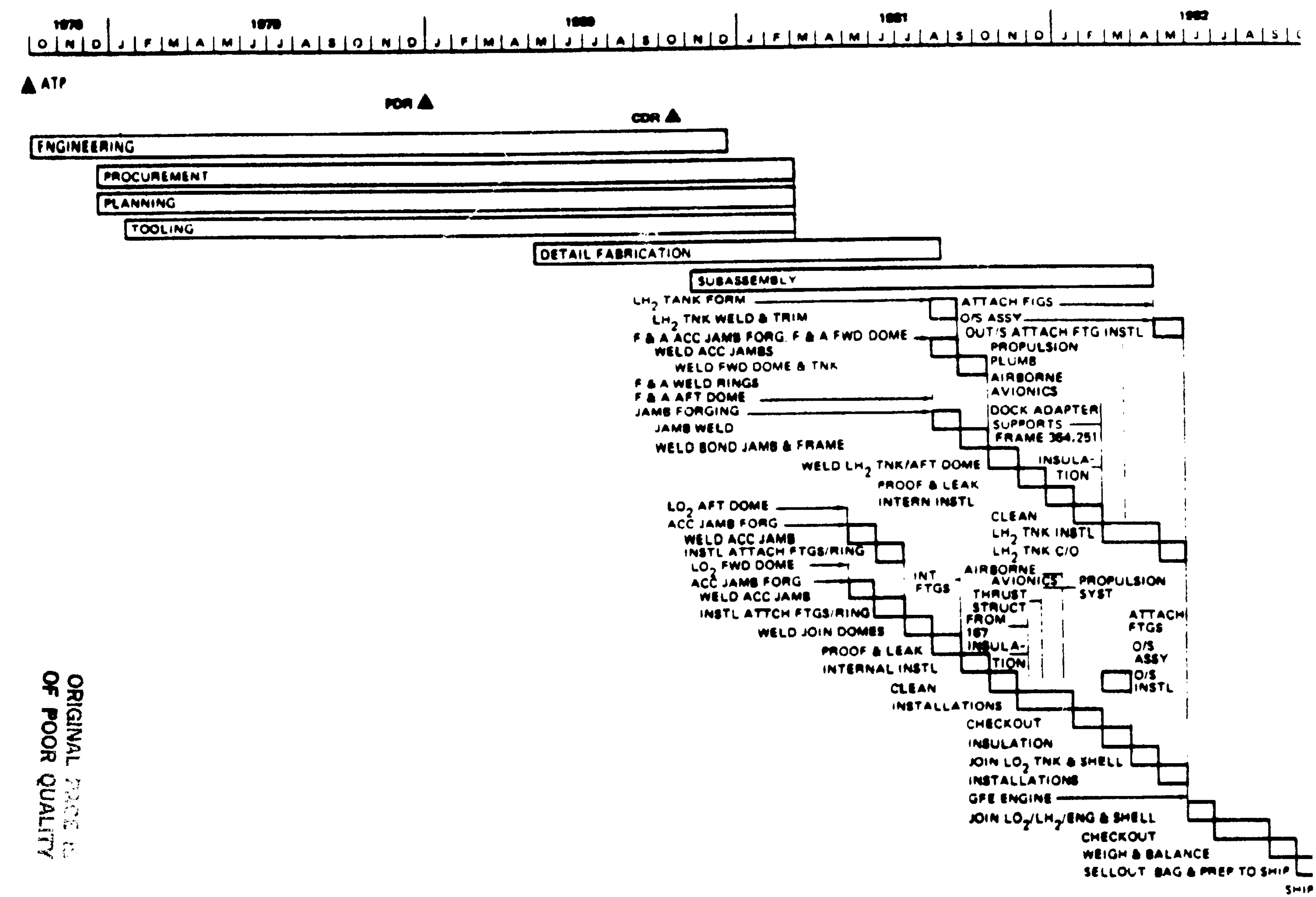


Figure 5-3. Space Tug Manufacturing Plan/Flow/Time – Option 3I



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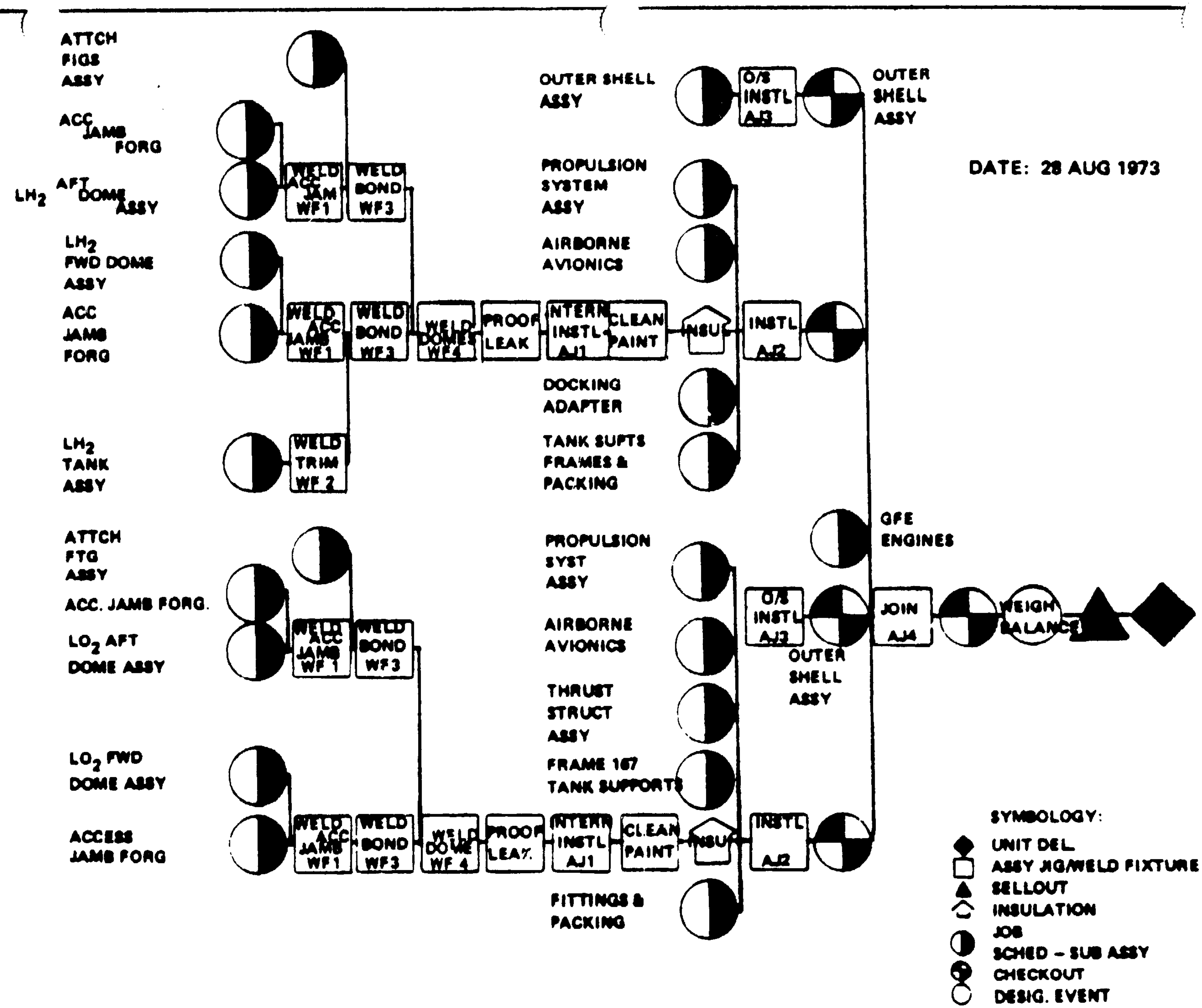

Figure 5-5. Space Tug System Study (Cryogenic) – Peak Rate Tree Chart (Max Rate 4 Per Year) – Option 1

The manufacturing plan outlined in this section is structured as follows:

- Fabrication and Subassembly (structures) plan and Flow Plans.
- Tank Bonding and Insulation plan and Flow Plans
- Final Assembly and Final Joining Plan and Flow Plans
- Propulsion Fabrication and Subassembly Plan and Flow Plans
- Avionics Fabrication and Subassembly and Installation Plan and Flow Plans
- Production Acceptance Test Plan.

5.1.4.1 Fabrication and Subassembly Plan (Structures)

The fabrication and subassembly requirements for the manufacture of the structural components comprising the Space Tug are state-of-the-art and wil not require the development of unique manufacturing processes. Low cost "s tooling i.e., layout templates, router/blocks, drop hammer dies, etc., will used extensively where practical. The LH_2 and LO_2 domes will be subcontrac to a vendor that currently has the capability to manufacture a one piece do

The fusion joining of the LH_2 tanks and the LO_2 tanks will be accomplished using the latest TIG welding techniques. The welding process employed in the manufacture of the Space Tug LH_2 and LO_2 tanks is fully discussed in Volume 8, Section 4.5 Summary Analysis/Philosophy.

The manufacturing requirements for each of the Space Tug components are out lined in the Space Tug fabrication flow plans, see typical flow plans in Figure 5-6.

5.1.4.2 Flight Articles

MDAC does not plan to provide dedicated flight test articles, as the high reliability and reuseability stressed in the initial design, and proven in development tests will assure flight worthy hardware. Manufacturing will produce 5 initial configuration flight vehicles and eleven phased up final configured flight vehicles. (See Volume 4, Book 3, Section 2 for mission accomplishment requirements.) Manufacture of the flight articles is descr in Section 4.1.2 together with the production flow for test integration, i lation and checkout.

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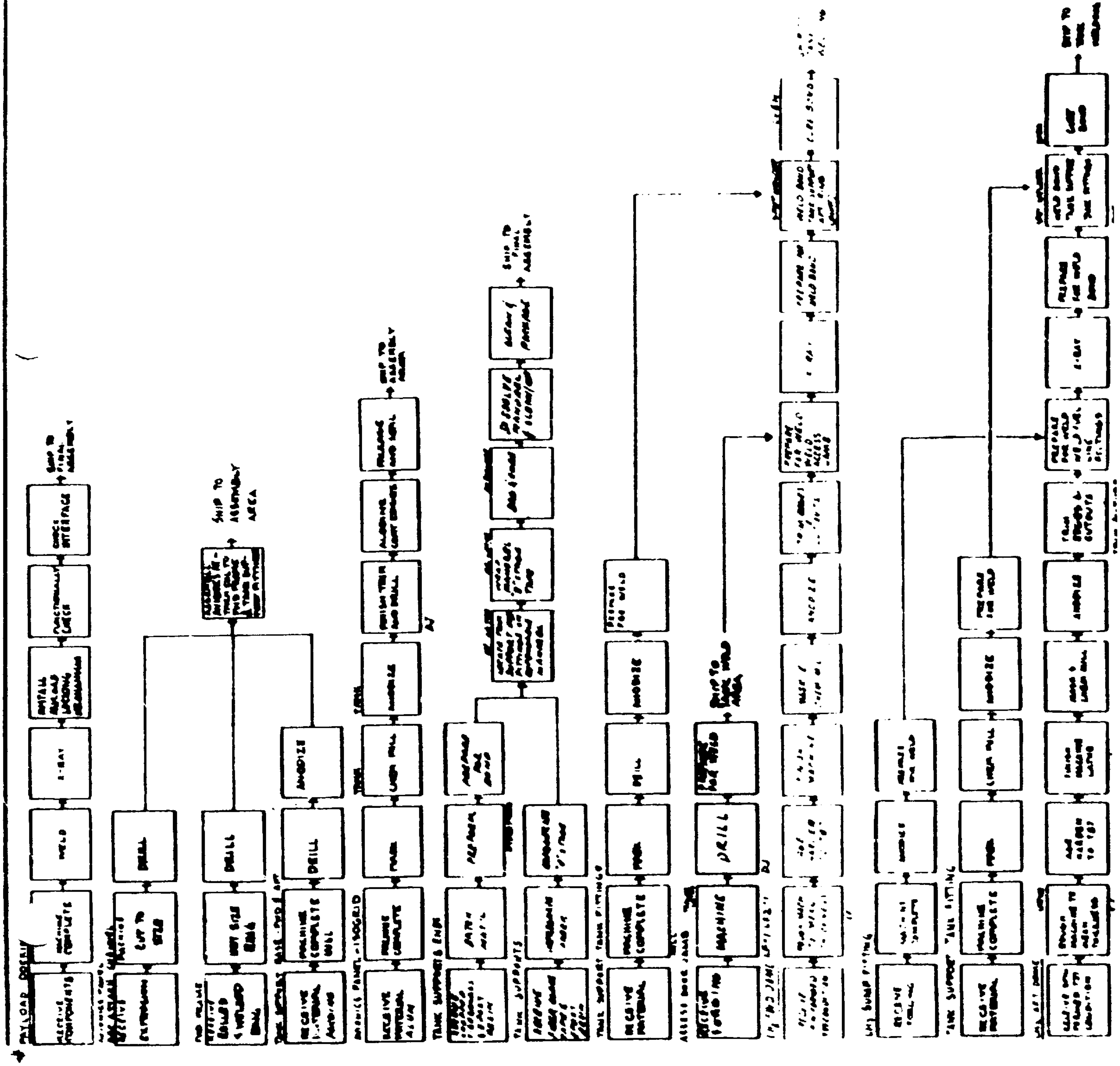


The final assembly and final joining line sequence flow are outlined in the flow plan. The LO_2 and the LH_2 tanks are built up as modular assemblies in horizontal mode. The LO_2 and the LH_2 subassembly jigs are then mated per le pins and index points and the final joining, installations, and checkout are accomplished.

5.2 FACILITIES

The requirements developed by operations analysis in the areas of manufacturing test, integration, checkout, launch, recovery, refurbishment, and storage were matched against existing, modified, and new facilities on the basis of availability, compatibility, and cost.

It was determined that facilities are not configuration sensitive; cost is not a determining factor in selection, since existing facilities can be utilized for most requirements.

Tug facilities at ETR will be satisfied by one new building and by modification and refurbishment of existing buildings and by use of Orbiter facilities that can be expanded or adapted to include Tug service.

At WTR construction of a new Payload Processing facility together with use of programmed Shuttle facilities expanded to satisfy Tug needs will provide the support required.

Manufacturing facilities will be based on existing MDAC plant and equipment at Huntington Beach, California, modifed and augmented by autoclaves-presses, etc. as required to produce Tug.

Production testing will be done at Huntington Beach. Some vehicle tests will be accomplished at NASA facilities at Huntsville and AEDC facilities at Tullahoma. Only such GSE as is needed for handling, loading, and other Tug peculiar requirements will be provided at test facilities.

Tabulations of all facility requirements, their cost, location, and lead times are shown in Tables 5-1 and 5-2.

5.3 VEHICLE TEST PROGRAM

A development test program envolops SR&T; development and qualification testing of parts, components, subassemblies, and assemblies of subsystems; reliability testing of selected items; repairability/maintainability testing of the smaller items; development, qualification, maintenance, and maintainability

Table 5-1

OPERATIONAL FACILITIES SUMMARY

Facility	Origin	KSC	WT
Tug Processing Facility	Modified KSC Bldg M7-355	$ 500,000	
DOD Payload Processing Facility	New	500,000	
Payload Processing Facility	New		$ 75C
Maintenance and CO Facility	Modified Shuttle Facility	10,000	
Maintenance and CO Facility	Modified Shuttle Facility		1C
Launch Service Structure	Modified Shuttle Facility	350,000	
Launch Service Structure	Modified Shuttle Facility		35C
Launch Control Center	Modified Shuttle Facility	10,000	
Launch Control Center	Modified Shuttle Facility		
Safing Facility	Modified Shuttle Facility	0	
Safing Facility	Modified Shuttle Facility		
Storable Propellant Facility	Modified Shuttle Facility	0	
Storable Propellant Facility	Modified Shuttle Facility		
Vertical Assembly Building	Modified Shuttle Facility	10,000	
Vertical Assembly Building	Modified Shuttle Facility		10
		$1,380,000	$1,120

Table 5-2

SPACE TUG STUDY

ADDITIONAL MANUFACTURING FACILITIES

Description	Lead Time	ROM Cost Option 1 and 3	ROM Cost Option
1. Aging over 20 ft x 20 ft x 8 ft (325°F)	6 months	$ 30,000	
2. Autoclave 16 ft dia x 12 ft long (600°F)	10 months	130,000	
3. Chem-mill facility 2 tanks 20 ft x 20 ft x 12 ft	10 months	200,000	
4. Anodize facility 20 ft x 20 ft x 10 ft tanks	4 months	200,000	
5. Clean room/10 ton bridge crane 5000 sq ft (100,000 class)	8 months	250,000	
6. Acoustic emission test equipment (PATE)		150,000	
7. Acoustic emission test equipment (PATE)		75,000	
			$ 1,035,0
8. Curing oven 16 ft x 16 ft x 8 ft (600°F)	6 months		60,0
TOTAL		1,035,000	1,095,0

TEST FACILITIES

	NASA	DOD
1. MDAC Huntington Beach Labs	0	0
2. NASA Huntsville High Vacuum Facility	0	250,000
3. AEDC Tullahoma Mark 4 Chamber	1,250,000	0

completed CEI.

The acquisition of assurance of reusability of the cryogenic Space Tug throu equipment life, maintainability, and/or refurbishment, begins with design an continues through component and vehicle level testing to mission operations. Design for high reliability and judiciously planned and implemented testing must be used to insure the specified reusability and life of the Space Tug.

The most cost effective program combines four philosophies pertinent to desi analyses and test:

A. Select existing hardware which is shown to have survived space flig
B. Design new subsystem hardware to survive an economically reasonable portion of Tug life.
C. Determine, through reliability analyses, that component reliability meets Tug requirements and that failures which may occur must be considered random failures.
D. Determine that a component/subassembly/assembly/subsystem cannot be removed and replaced through scheduled or unscheduled maintenance; design for survival through Tug environmental criteria beyond expec life.

The majority of the components intended to comprise this configuration eithe have been developed for use in previously produced space vehicles, are standard components qualified for space vehicle applications, or will requi little modification to meet Space Tug specifications. For those components requiring new or further development or requalification, an economically feasible population will be selected for the appropriate type of testing. Further, the level of hardware assembly at which verification of a given ite can be adequately achieved, i.e., component, subassembly, assembly, etc., w be evaluated. To the maximum extent possible, qualification of hardware included in the design will be achieved through means other than testing, i. analysis, inspection, demonstration, or simulation. Emphasis will be place on repairability within each analysis or during testing.

combination of design selection of high reliability/long life components and parts, and the component verification approach outlined above should yield an approximate 10 percent reduction of operational maintenance and refurbishment costs. DDT&E costs will be higher due to testing, and its associated population requirements, to provide reliability and life; however, this cost is non recurring and will produce a reduction in recurring costs by lowering the incidence of both scheduled and unscheduled maintenance and refurbishment.

5.3.1 Vehicle Ground Test Summary

Tests to be conducted with the major test articles are summarized in Table 5-3. The testing program is designed to provide the maximum confidence possible, consistent with minimum DDT&E funding of this option. Test descriptions and estimates are provided in Volume 8.

5.3.2 Flight Test - 3I

Flight test data will be acquired in conjunction with normal mission performance. Flight test objectives are aimed at verifying that the Space Tug can perform assigned missions within the specified mission within the specified mission envelope of performance and time requirements.

The first produced Tug will be equipped with special flight test instrumentation in support of the following objectives:

A. Propellant settling.

B. Propellant utilization.

C. Propellant feedline and engine thermal conditioning.

D. Propellant conditioning.

E. Zero-g heat transfer.

F. Avionics cold plate temperature stabilization.

G. Vibration levels of selected critical installations.

Information will be obtained from this instrumentation during the first two flights flown by this Tug. The flights will carry spacecraft for orbital placement. Following termination of the second flight, the flight test instrumentation will be removed and the Tug processed through a normal turnaround cycle. This Tug will then continue normal operations within the fleet.

Table 5-3

VEHICLE TEST

Test	3I NASA	3I DOD	3I IOC CHG	3F NASA	3F DOD	3F IOC CHG	03
Pressure Cycle Tanks (Development)	X	X	X				
Pressure Burst Tanks (Development)	X	X	X				
Pressure Cycle/Proof Tanks and Static Loading of Remainder of Structures Subsystems (Qualification)	X	X	X				
Maintenance ($\bar{M}$) Procedures Verification (DT&E, IOT&E) - Development Fixture	X	X	X	X	X	X	X
Maintainability (M) Evaluation - Development Fixture	X	X	X	X	X	X	X
Propulsion Test Vehicle - Cold Flow (CAT I RL10 Engine)	X	X	X				
Propulsion Test Vehicle - Static Firing (Other Than CAT I RL10)							X
Maintainability (M) Evaluation - PTV	X	X	X				X
Integrated Avionics Test Unit (IATU) (DT&E, IOT&E)	X	X	X	X	X	X	X
Maintainability (M) Evaluation - IATU	X	X	X	X	X	X	X
Flight Control Simulation (Deployment Only)	X	X	X				
Flight Control Simulation (Deployment and Retrieval)				X	X	X	X
Transportation and Handling Procedures Verification,	X	X	X				

Table 5-3

VEHICLE TEST (Continued)

Test	3I NASA	3I DOD	3I IOC CHG	3F NASA	3F DOD	3F IOC CHG	C
Thermal				X	X	X	
EMC - Flight Test Article, Manufacturing	X	X	X	X	X	X	
EMC - First Delivered Tug, ETR	X	X	X	X	X	X	
EMC - First Delivered Tug, WTR	X	X	X	X	X	X	
M - Flight Test Article, ETR	X	X	X	X	X	X	
M - Flight Test Article, WTR	X	X	X	X	X	X	
Flight Support Equipment with an IVU	X	X	X				
Flight Support Equipment with an IVU and the Orbiter (Egress-Ingress)	X	X	X				
Flight Test Operations Egress-Ingress Maneuver Verification Using the IVU	X	X	X				
Flight Test Operations Two Flights with Operational Missions	X		X				
Flight Test Operations - Two Flights, Dedicated		X					
Flight Test Operations - One Flight with Operational Mission				X		X	
Flight Test Operations - One Flight, Dedicated					X		

Flight test data will be acquired in conjunction with normal mission performance. Flight test objectives are aimed at verifying that the Space Tug can perform assigned missions within the specified mission envelope of performance and time requirements.

The first produced Tug will be equipped with special flight test instrument in support of the following objectives:

A. Zero-g heat transfer.

B. Avionics cold plate temperature stabilization.

C. Vibration levels of selected critical installations.

Information will be obtained from this instrumentation during the first fli flown by this Tug. The flight will carry spacecraft for orbital placement. Following termination of the flight, the flight test instrumentation will b removed and the Tug processed through a normal turnaround cycle. This Tug will then continue normal operations within the fleet.

5.4 SCHEDULE SUMMARY (NASA) ACQUISITION

The schedule (Figure 5-7) for Space Tug Option 3 is based on Phase C/D design, development and operations authority to proceed (ATP) in October 19 Design, development, test and evaluation (DDT&E) for Increment I (interim configuration) and Increment II (final configuration) requires 54 months an 62 months respectively and is complete at the first Space Tug operational launch of each configuration. 10.7 years of flight operations are assumed beginning with the first operational launch and are complete in 1990.

Space Tug Preliminary Design Reviews (PDR) are scheduled for 17 months and 51 months after ATP to establish firm phased vehicle configurations. Critical Design Reviews (CDR) will be completed at 28 months and 60 months after ATP, for Increment I and Increment II respectively, to assure that design requirements have been met.

The ground test program will use subsystem models for concept and design development and design qualification. Qualifications of subsystems will be complete in March 1979 and November 1981, 41 months and 73 months respectiv

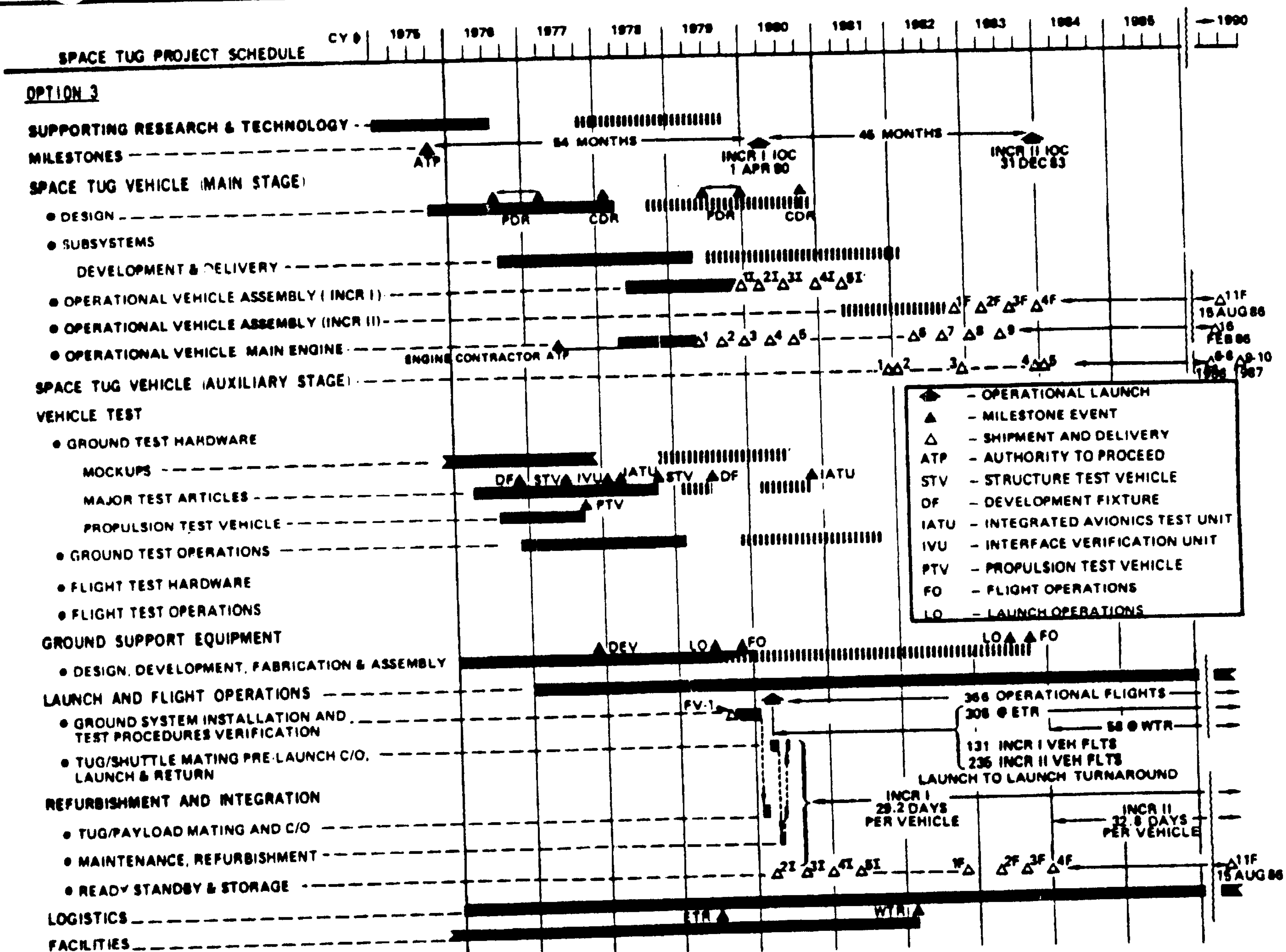


Figure 5-7. Schedule Summary (NASA)

for subsystem integration and interface verification activities. Two space vehicles are required at IOC to support the initial requirements of three flights in the first year of operations. A total of five Increment I vehic and eleven Increment II vehicles are produced and delivered over a period o 6.6 years. Vehicles are stored at the launch facility and used as required support launch and refurbishment operations.

Increment I operational flights start at IOC, April 1, 1980, and complete w the 131st flight in 1989. Increment II operational flights start at Phase IOC, December 31, 1983, and complete with the 336 flight in 1990. Three hundred eight flights are launched from ETR and 58 flights are launched fro WTR.

5.5 COST SUMMARY (NASA ACQUISITION)

Summary costs for this program option are presented in the following charts

A. Summary Cost Tabulation

B. Cost Summaries

C. Cost Per Flight Data Sheets.

Reference is made to Volume 8, Book 1, for detail cost information.

The Summary Cost Tabulation (Table 5-4) is derived from the LEADER II Cost Printout. The Cost Summaries (Figures 5-8 through 5-10) present a Technic mary, a Schedule Summary, an Annual Funding Summary, and a Cumulative Fundi Summary, for each phase (Initial and Final) and Total Project for the phase developed Option 3. The Cost Per Flight Data sheets Tables 5-5 through 5-1 have been prepared in in accordance with NASA Direction (Reference: Lette PD-TUG-P (015-74), dated August 3, 1973, from J. A. Stucker, Manager, Program Planning and Control, to A. G. Crillion, COR, PD-TUG-C).

Table 5-4

PROGRAM OPTION NO. 3

SUMMARY COST TABULATION

1973 DOLLARS IN MILLIONS

TOTAL PROGRAM COSTS

	INITIAL	FINAL	TOTAL
DDT&E	190.10	88.82	278.92
PRODUCTION	98.59	176.81	275.53
OPERATIONS	88.56	204.46	293.02
TOTAL	377.26	470.08	847.47

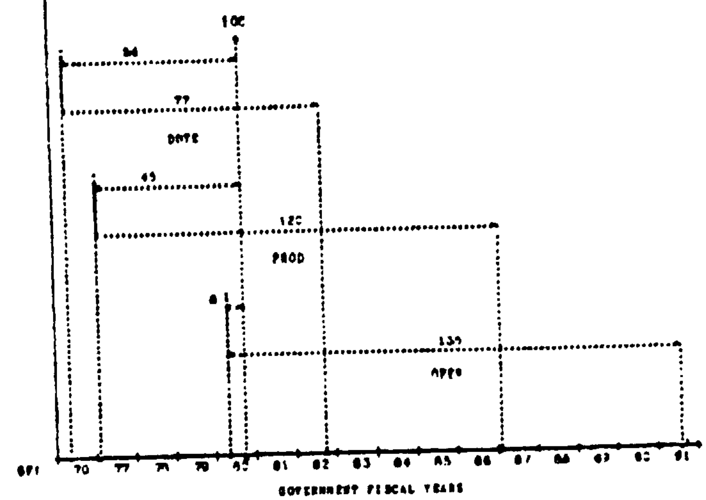
UNIT COSTS

	INITIAL	FINAL
VEHICLE MAIN STAGE		
FIRST PRODUCTION UNIT-HARDWARE	14.68	17.40
AVERAGE UNIT (INCLUDING SUPPORT)	16.62	15.50
VEHICLE AUXILIARY STAGE		
AVERAGE UNIT (INC. STARTUP)	5.15	0.91
AVERAGE COST PER FLIGHT		
MODE 1 - NASA	1.05	0.70
MODE 1 - DOD	1.06	0.72
MODE 2 - NASA	Not Required	15.97
MODE 2 - DOD	Not Required	
MODE 3 - NASA	6.20	1.61
MODE 3 - DOD	6.21	Not Required

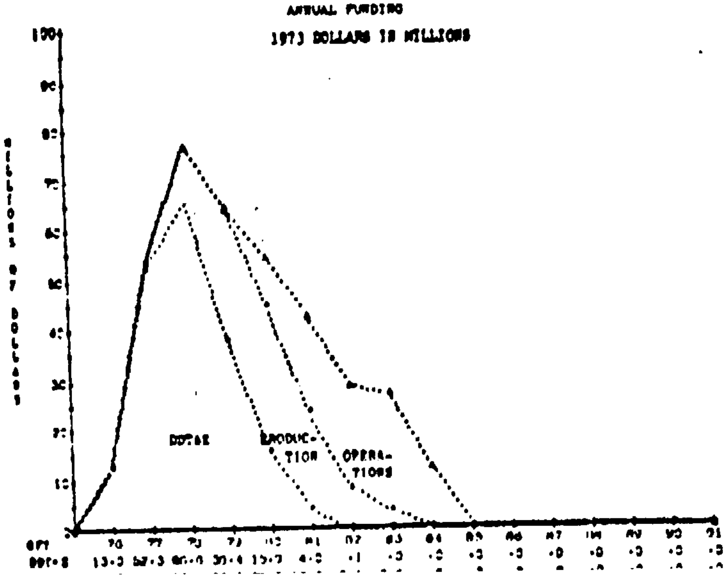
TECHNICAL CHARACTERISTICS - OPTION NO. 3 - INITIAL (INCREMENT I)*
VBS 320 TOTAL SPACE TUG PROJECT

MAJOR HARDWARE	
SPACE TUG VEHICLE MAIN STAGE	3 VEHICLES
SPACE TUG VEHICLE AUXILIARY STAGE	3 STAGES
OTHER SYSTEM ELEMENTS	
PROJECT MANAGEMENT	
SYSTEMS ENGINEERING AND INTEGRATION	
LOGISTICS	TRANSP., TRAINING, SIMULATION
FACILITIES	FACTORY, TEST, ETR, WTR
GROUND SUPPORT EQUIPMENT	FACTORY, ETR, WTR
VEHICLE TEST	FTV, MAJOR TEST ARTICLES
LAUNCH OPERATIONS - WTR	8 LAUNCHES
LAUNCH OPERATIONS - ETR	74 LAUNCHES
FLIGHT OPERATIONS - NASA	48 FLIGHTS
FLIGHT OPERATIONS - DOD	34 FLIGHTS
REFURBISHMENT AND MAINTENANCE - WTR	8 REFURBS
REFURBISHMENT AND MAINTENANCE - ETR	70 REFURBS

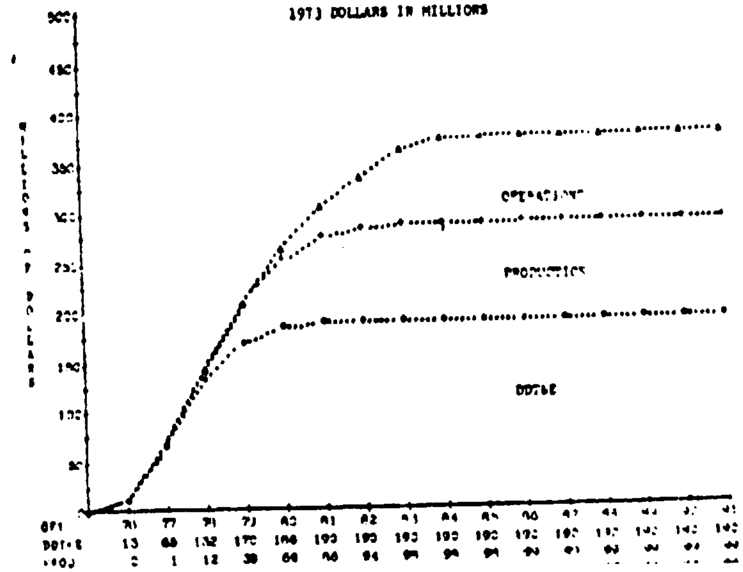
PROGRAM OPTION NO. 3 - INITIAL
VBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT



PROGRAM OPTION NO. 3 - INITIAL
VBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT
ANNUAL FUNDING
1973 DOLLARS IN MILLIONS



PROGRAM OPTION NO. 3 - INITIAL
VBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT
CUMULATIVE FUNDING
1973 DOLLARS IN MILLIONS



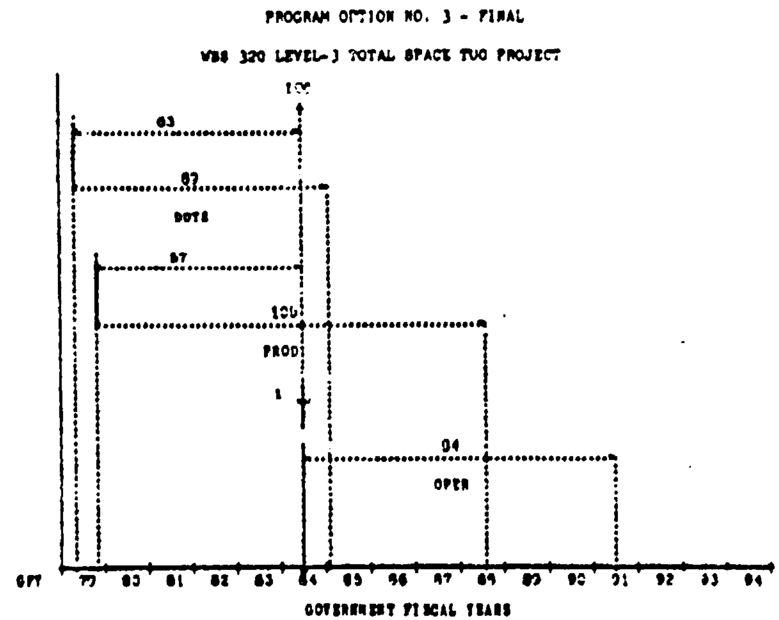
TECHNICAL CHARACTERISTICS - OPTION NO. 3F (INCREMENT II)*
WBS 320 TOTAL SPACE TUG PROJECT

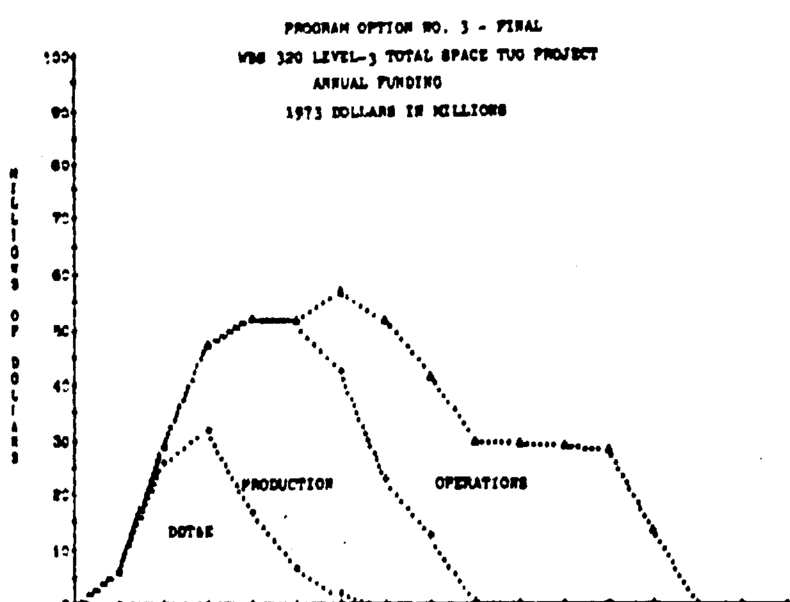
MAJOR HARDWARE

SPACE TUG VEHICLE MAIN STAGE	11 VEHICLES
SPACE TUG VEHICLE AUXILIARY STAGE	7 STAGES

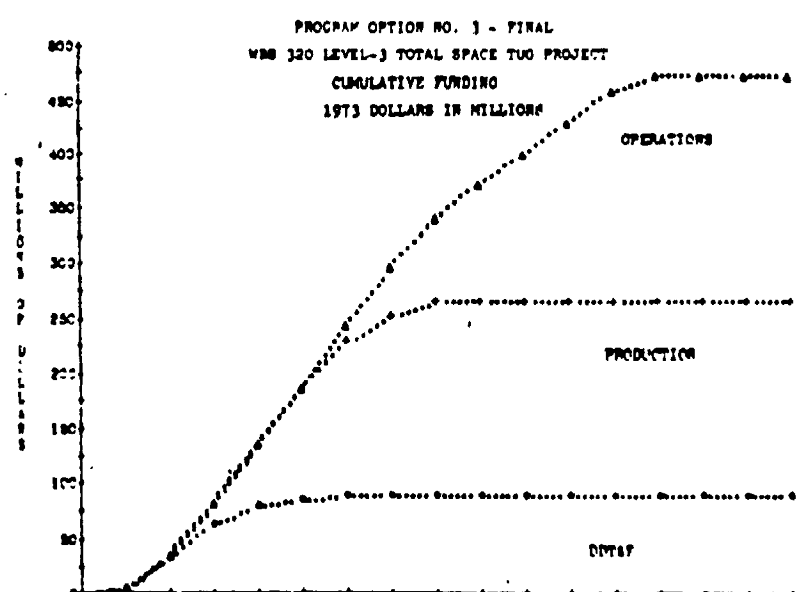
OTHER SYSTEM ELEMENTS

PROJECT MANAGEMENT	
SYSTEMS ENGINEERING AND INTEGRATION	
LOGISTICS	TRANSP., TRAINING, SIMULATION
FACILITIES	FACTORY, TEST, ETR, WTR
GROUND SUPPORT EQUIPMENT	FACTORY, ETR, WTR
VEHICLE TEST	FTV, MAJOR TEST ARTICLES
LAUNCH OPERATIONS - WTR	50 LAUNCHES
LAUNCH OPERATIONS - ETR	225 LAUNCHES
FLIGHT OPERATIONS - NASA	172 FLIGHTS
FLIGHT OPERATIONS - DOD	116 FLIGHTS
REFURBISHMENT AND MAINTENANCE - WTR	50 REFURBS
REFURBISHMENT AND MAINTENANCE - ETR	230 REFURBS





GFY	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
DDT&E	6.1	25.5	31.7	16.0	6.7	2.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
PROD	.0	3.5	15.6	36.6	45.1	40.3	22.9	12.7	.8	.4	.0	.0	.0	.0	.0	.0
OPER	.0	.0	.0	.0	.0	14.7	29.5	29.5	29.5	29.5	29.3	28.7	13.2	.0	.0	.0
TOTAL	6.1	29.1	47.3	52.1	51.8	57.2	52.4	42.2	30.3	29.9	29.8	28.7	13.9	.0	.0	.0



GFY	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
DDT&E	6	32	63	80	87	89	89	89	89	89	89	89	89	89	89	89
PROD	0	4	19	56	100	140	163	176	176	177	177	177	177	177	177	177
OPER	0	0	0	0	0	18	44	74	103	133	162	191	205	205	205	205
TOTAL	6	36	82	134	186	243	295	338	368	398	427	456	472	472	472	472

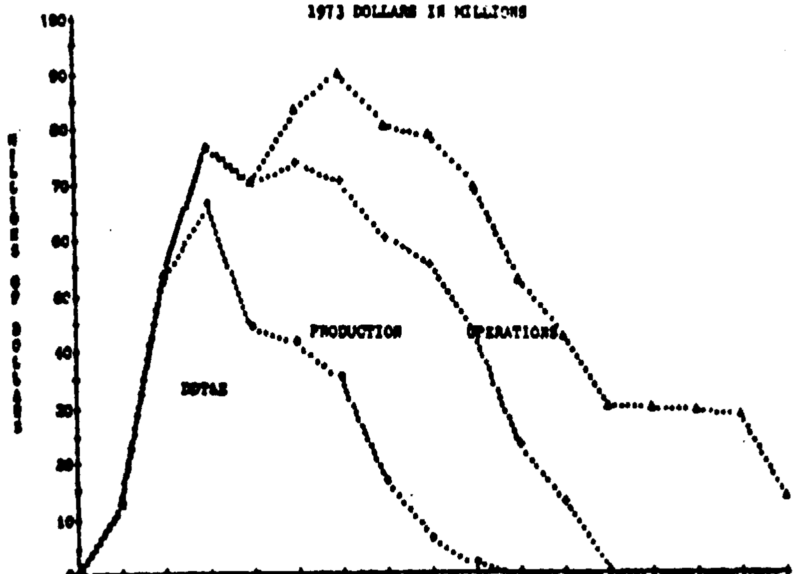
Fig. 5-9
Cost Summary – Program Option No. 3 – Final

TECHNICAL CHARACTERISTICS - OPTION NO. 3 TOTAL

WBS 320 - LEVEL-3 TOTAL SPACE TUG PROJECT

THE TECHNICAL CHARACTERISTICS ARE EQUIVALENT TO THE SUM OF THE INCREMENTAL CHARACTERISTICS. HOWEVER, A MERE SUMMATION WOULD NOT BE MEANINGFUL. THEREFORE, REFERENCE IS MADE TO THE RESPECTIVE CHARACTERISTICS FOR THE INITIAL PHASE AND THE FINAL PHASE.

PROGRAM OPTION NO. 3 - TOTAL
WBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT
ANNUAL FUNDING
1973 DOLLARS IN MILLIONS



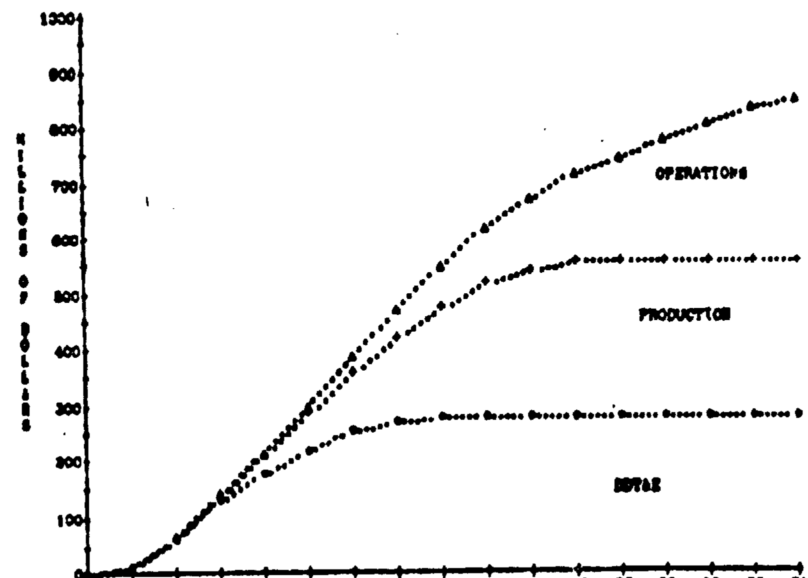
GFY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E	13.0	52.3	66.6	44.8	41.8	30.7	16.7	6.7	2.2	.0	.0	.0	.0	.0	.0	.0
PROD	.0	1.4	10.1	29.0	30.4	39.1	43.6	40.7	45.9	23.1	12.9	.8	.4	.0	.0	.0
OPER	.0	.0	.0	.0	9.8	19.4	23.6	23.8	26.0	27.9	29.9	29.9	29.9	29.9	29.1	14.1
TOTAL	13.0	53.7	76.7	73.8	83.7	90.2	80.9	70.2	69.9	53.3	42.8	30.7	30.3	29.9	29.1	14.1

PROGRAM OPTION NO. 3 TOTAL

WBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT

A COMPOSITE SCHEDULE WOULD NOT BE MEANINGFUL, SINCE TWO IOC DATES WOULD BE REFERENCED FOR THE T_S AND T_D VALUES. THEREFORE, REFERENCE IS MADE TO THE RESPECTIVE SCHEDULES FOR THE INITIAL PHASE AND THE FINAL PHASE.

PROGRAM OPTION NO. 3 - TOTAL
WBS 320 LEVEL-3 TOTAL SPACE TUG PROJECT
CUMULATIVE FUNDING
1973 DOLLARS IN MILLIONS



GFY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E	13	66	132	176	218	254	270	277	279	279	277	278	279	279	279	279
PROD	0	1	12	38	70	109	149	197	238	261	274	275	276	276	276	275
OPER	0	0	0	0	10	20	50	74	100	130	163	193	223	250	279	293
TOTAL	13	66	143	213	297	387	468	547	617	673	713	744	774	804	833	847

Tug/Shuttle mating and checkout	$ 11,2[illegible]	
Tug/Payload mating and checkout	21,742	
Launch checkout	23,917	
Countdown	31,150	
Propellant and gases	6,510	
Post flight safing	25,558	
Site services and support	62,742	
		$ 394,877
MAINTENANCE AND REFURBISHMENT		
Scheduled maintenance and refurbishment	$ 35,200	
Unscheduled maintenance and refurbishment	8,667	
Tug engine maintenance and refurbishment	21,515	
Tug vehicle spares	74,365	
Tug engine spares	19,298	
Post maintenance checkout	2,175	
Refurbishment requirements planning	9,825	
Depot maintenance	273,832	
AL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 585,738
		$ 284,500
FLIGHT OPERATIONS		
Mission planning	$ 48,200	
Flight control	159,900	
Flight evaluation	45,600	
Flight software	30,800	
		$ 184,988
OPERATIONS SUPPORT		
Airborne software update	$ 10,202	
GSE maintenance	45,602	
Sustaining engineering	40,685	
Program management	27,779	
Transportation and handling	1,229	
Inventory control and warehousing	12,783	
Facilities maintenance	14,873	
GSE software update	31,835	
		$ -0-
EXPENDABLE VEHICLE MAIN STAGE		$ -0-
EXPENDABLE VEHICLE AUXILIARY STAGE		

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Tug/Shuttle mating and checkout	$ 17,347	
Tug/Payload mating and checkout	21,923	
Prelaunch checkout	24,294	
Countdown	31,665	
Propellant and gases	6,391	
Post flight safing	25,912	
Site services and support	63,541	
MAINTENANCE AND REFURBISHMENT		$ 393,0
Scheduled maintenance and refurbishment	$ 35,653	
Unscheduled maintenance and refurbishment	8,776	
Tug engine maintenance and refurbishment	21,107	
Tug vehicle spares	72,956	
Tug engine spares	18,932	
Post maintenance checkout	2,329	
Refurbishment requirements planning	9,918	
Depot maintenance	223,401	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 556,3
FLIGHT OPERATIONS		$ 294,9
Mission planning	$ 49,100	
Flight control	171,800	
Flight evaluation	41,800	
Flight software	32,200	
OPERATIONS SUPPORT		$ 181,
Airborne software update	$ 10,009	
GSE maintenance	44,738	
Sustaining engineering	39,915	
Program management	27,253	
Transportation and handling	1,206	
Inventory control and warehousing	13,541	
Facilities maintenance	14,5[illegible]1	
GSE software update	31,232	
EXPENDABLE VEHICLE MAIN STAGE		$ -0-
EXPENDABLE VEHICLE AUXILIARY STAGE		$ -0-

ug/Shuttle mating and checkout	$ 19,375	
ug/Payload mating and checkout	26,961	
r... unch checkout	23,059	
ountdown	37,575	
ropellant and gases	6,427	
ost flight safing	27,189	
ite services and support	65,468	
ITENANCE AND REFURBISHMENT		$ 225,716
Scheduled maintenance and refurbishment	$ 38,266	
Unscheduled maintenance and refurbishment	7,477	
Tug engine maintenance and refurbishment	9,143	
Tug vehicle spares	30,905	
Tug engine spares	3,723	
Post maintenance checkout	1,914	
Refurbishment requirements planning	9,132	
Depot maintenance	125,156	
... GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 431,800
GHT OPERATIONS		$ 186,800
Mission planning	$ 40,100	
Flight control	81,500	
Flight evaluation	44,900	
Flight software	20,300	
RATIONS SUPPORT		$ 84,882
Airborne software update	$ 10,079	
GSE maintenance	1,054	
Sustaining engineering	25,040	
Program management	20,790	
Transportation and handling	807	
Inventory control and warehousing	14,434	
Facilities maintenance	0	
GSE software update	12,678	
PENDABLE VEHICLE MAIN STAGE		$ 0
PENDABLE VEHICLE AUXILIARY STAGE		$ 0

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Tug/Shuttle mating and checkout	$ [illegible]	
Tug/Payload mating and checkout	25,853	
Prelaunch checkout	22,102	
Countdown	36,109	
Propellant and gases	6,468	
Post flight safing	26,202	
Site services and support	62,784	
MAINTENANCE AND REFURBISHMENT		$ 229,9
Scheduled maintenance and refurbishment	$ 36,675	
Unscheduled maintenance and refurbishment	7,153	
Tug engine maintenance and refurbishment	9,202	
Tug vehicle spares	31,103	
Tug engine spares	3,747	
Post maintenance checkout	1,834	
Refurbishment requirements planning	8,743	
Depot maintenance	131,468	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 427,
		$ 209,(
FLIGHT OPERATIONS		
Mission planning	$ 49,400	
Flight control	82,000	
Flight evaluation	55,400	
Flight software	22,800	
OPERATIONS SUPPORT		$ 85,
Airborne software update	$ 10,144	
GSE maintenance	1,060	
Sustaining engineering	25,200	
Program management	20,924	
Transportation and handling	813	
Inventory control and warehousing	14,577	
Facilities maintenance	-0-	
GSE software update	12,759	
EXPENDABLE VEHICLE MAIN STAGE		$
EXPENDABLE VEHICLE AUXILIARY STAGE		$

...NCH OPERATIONS		
Tug/Shuttle mating and checkout	$ 19,375	
T /Payload mating and checkout	26,961	
Prelaunch checkout	23,039	
Countdown	37,575	
Propellant and gases	1,427	
Post flight safing	27,189	
Site services and support	65,468	
...NTENANCE AND REFURBISHMENT		$ 0
Scheduled maintenance and refurbishment	$	
Unscheduled maintenance and refurbishment		
Tug engine maintenance and refurbishment		
Tug vehicle spares		
Tug engine spares		
Post maintenance checkout		
Refurbishment requirements planning		
Depot maintenance		
... GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 206,080
...IGHT OPERATIONS		$ 186,800
Mission planning	$ 40,100	
Flight control	81,500	
Flight evaluation	44,900	
Flight software	20,300	
...ERATIONS SUPPORT		$ 84,882
Airborne software update	$ 10,079	
GSE maintenance	1,050	
Sustaining engineering	25,040	
Program management	20,790	
Transportation and handling	807	
Inventory control and warehousing	14,450	
Facilities maintenance	0	
... software update	12,678	
...PENDABLE VEHICLE MAIN STAGE		$ 15,500,000
...PENDABLE VEHICLE AUXILIARY STAGE		$ -0-

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Tug/Payload mating and checkout	21,142	
Prelaunch checkout	23,917	
Countdown	31,150	
Propellant and gases	6,510	
Post flight safing	25,558	
Site services and support	62,742	
		$ 394,8
MAINTENANCE AND REFURBISHMENT		
Scheduled maintenance and refurbishment	$ 35,200	
Unscheduled maintenance and refurbishment	8,667	
Tug engine maintenance and refurbishment	21,515	
Tug vehicle spares	74,365	
Tug engine spares	19,248	
Post maintenance checkout	2,175	
Refurbishment requirements planning	9,825	
Depot maintenance	223,832	
		$ 555,9
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 282,5
FLIGHT OPERATIONS		
Mission planning	$ 48,200	
Flight control	159,900	
Flight evaluation	43,600	
Flight software	30,800	
		$ 184,
OPERATIONS SUPPORT		
Airborne software update	$ 10,202	
GSE maintenance	45,602	
Sustaining engineering	40,685	
Program management	27,779	
Transportation and handling	6,229	
Inventory control and warehousing	12,783	
Facilities maintenance	14,873	
GSE software update	31,835	
		$
EXPENDABLE VEHICLE MAIN STAGE		$ 5,15
EXPENDABLE VEHICLE AUXILIARY STAGE		

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..g/Payload mating and checkout	[illegible]	
..relaunch checkout	24,29[illegible]	
..o.. ..own	31,665	
..ropellant and gases	6,391	
..ost flight safing	25,912	
..ite services and support	63,541	
..TENANCE AND REFURBISHMENT		$ 393,072
..cheduled maintenance and refurbishment	$ 35,653	
..nscheduled maintenance and refurbishment	8,776	
..ug engine maintenance and refurbishment	21,107	
..ug vehicle spares	72,956	
..ug engine spares	11,932	
..ost maintenance checkout	2,329	
..efurbishment requirements planning	9,918	
..epot maintenance	223,401	
..L GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 586,345
		$ 294,900
..H.. OPERATIONS		
..ission planning	$ 49,100	
..light control	171,800	
..light evaluation	41,800	
..light software	32,200	
..ATIONS SUPPORT		$ 181,[illegible]15
..irborne software update	$ 10,009	
..SE maintenance	44,[illegible]	
..ustaining engineering	39,915	
..rogram management	27,253	
..ransportation and handling	1,206	
..nventory control and warehousing	12,541	
..acilities maintenance	14,591	
..SE software update	31,282	
..ABLE VEHICLE MAIN STAGE		$ 0
..NDABLE VEHICLE AUXILIARY STAGE		$ 5,150,000

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[illegible]	23,089	
Prelaunch checkout	37,575	
Countdown	6,427	
Propellant and gases	27,189	
Post flight safing	65,468	
Site services and support		$ 225,7[illegible]
MAINTENANCE AND REFURBISHMENT		
Scheduled maintenance and refurbishment	$ 38,266	
Unscheduled maintenance and refurbishment	7,477	
Tug engine maintenance and refurbishment	9,143	
Tug vehicle spares	30,405	
Tug engine spares	3,723	
Post maintenance checkout	1,914	
Refurbishment requirements planning	9,132	
Depot maintenance	125,156	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 231,8[illegible]
		$ 186,8[illegible]
FLIGHT OPERATIONS		
Mission planning	$ 40,100	
Flight control	81,500	
Flight evaluation	44,100	
Flight software	20,300	
		$ 84,85[illegible]
OPERATIONS SUPPORT		
Airborne software update	$ 10,079	
GSE maintenance	1,054	
Sustaining engineering	25,040	
Program management	20,790	
Transportation and handling	807	
Inventory control and warehousing	14,434	
Facilities maintenance	0	
GSE software update	12,678	
		$ 1[illegible]
EXPENDABLE VEHICLE MAIN STAGE		
		$ 910,[illegible]
EXPENDABLE VEHICLE AUXILIARY STAGE		
		$ 1,613,[illegible]

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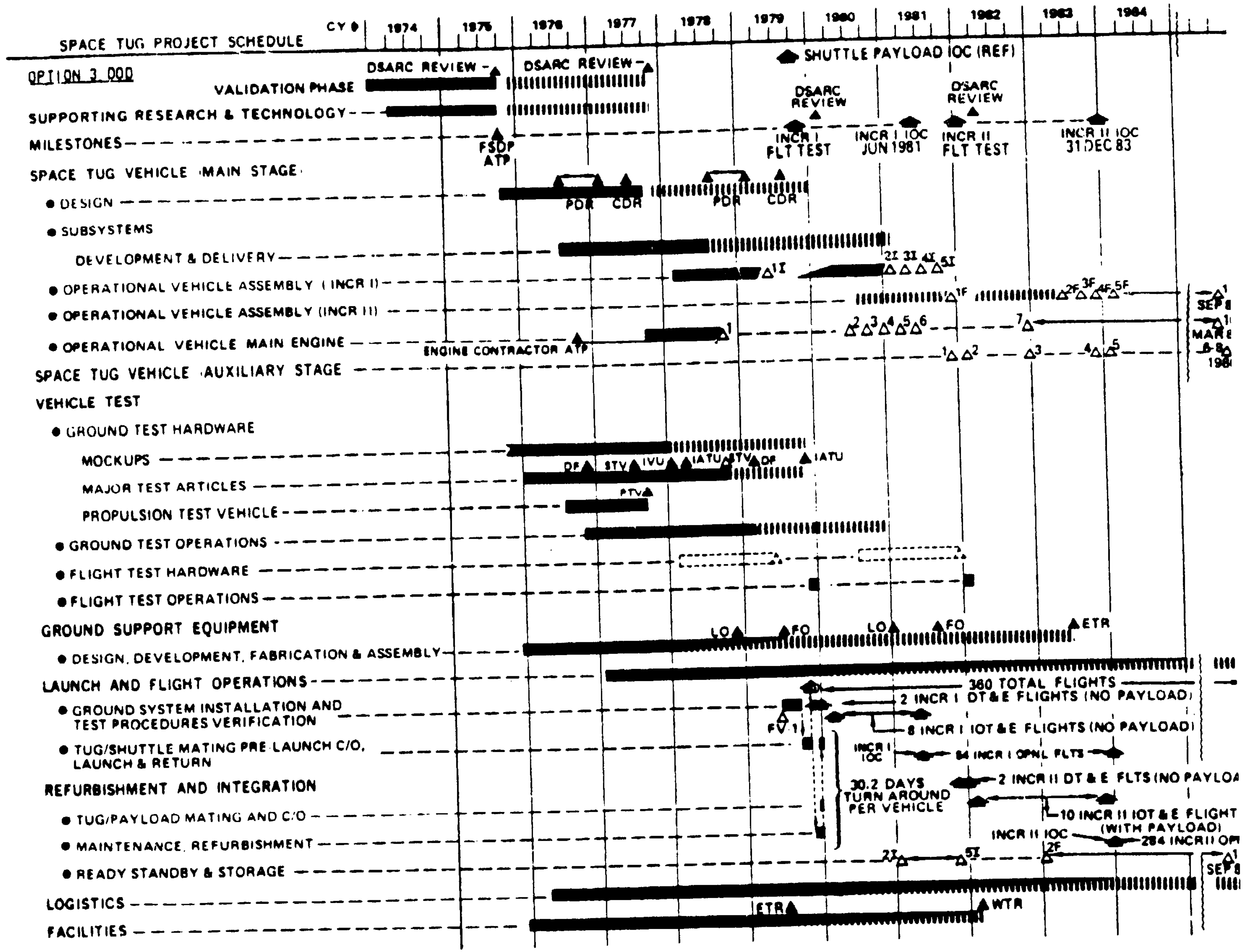
design, development, and operations, authority to proceed (ATP) in October 1975. Design, development, test, and evaluation (DDT&E) for Increment I (interim configuration) and Increment II (final configuration) requires 52 months and 75 months respectively and is complete following dedicated flight tests of each configuration. 10.8 years of flight operations are assumed beginning with the first payload launch in March 1980 and are complete in 1990.

Space Tug Preliminary Design Review (PDR) are scheduled for 16 months and 41 months after ATP, to establish firm phased vehicle configurations. Critical Design Reviews (CDR) will be completed at 22 months and 47 months after ATP, for Increment I and Increment II, respectively, to assure that design requirements have been met.

The ground test program will use subsystem models for concept and design development and design qualifications. Qualifications of subsystems will be complete in August 1978 and October 1980, 34 months and 60 months, respectively, after ATP. System level test articles will be used in the ground test program for subsystem integration and interface verification activities. One Space Tug vehicle is required to support the initial requirements of three flights in the first year of operations. A total of five Increment I vehicles and nine Increment II vehicles are produced and delivered over a period of 4.2 years. Vehicles are stored at the launch facility and used as required to support launch and refurbishment operations.

All Space Tug vehicles are produced in the same factory manufacturing and testing facilities and subjected to the same development, qualification, and production acceptance testing. The first unit of each increment is used as the full scale development phase flight test vehicle, and subsequently, to fly initial payload/IOT&E flights until the production vehicles become available. Each of the number one vehicles for Increment I and Increment II will be flown twice to validate operation, refurbishment, and maintenance. The vehicles are then made ready to start payload flights following DSARC reveiw and production go-ahead.



SPACE TUG PROJECT SCHEDULE
CY
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
OPTION 3.000
VALIDATION PHASE
SUPPORTING RESEARCH & TECHNOLOGY
MILESTONES
SPACE TUG VEHICLE (MAIN STAGE)
● DESIGN
● SUBSYSTEMS
DEVELOPMENT & DELIVERY
● OPERATIONAL VEHICLE ASSEMBLY (INCR I)
● OPERATIONAL VEHICLE ASSEMBLY (INCR II)
● OPERATIONAL VEHICLE MAIN ENGINE
SPACE TUG VEHICLE (AUXILIARY STAGE)
VEHICLE TEST
● GROUND TEST HARDWARE
MOCKUPS
MAJOR TEST ARTICLES
PROPULSION TEST VEHICLE
● GROUND TEST OPERATIONS
● FLIGHT TEST HARDWARE
● FLIGHT TEST OPERATIONS
GROUND SUPPORT EQUIPMENT
● DESIGN, DEVELOPMENT, FABRICATION & ASSEMBLY
LAUNCH AND FLIGHT OPERATIONS
● GROUND SYSTEM INSTALLATION AND TEST PROCEDURES VERIFICATION
● TUG/SHUTTLE MATING PRE-LAUNCH C/O, LAUNCH & RETURN
REFURBISHMENT AND INTEGRATION
● TUG/PAYLOAD MATING AND C/O
● MAINTENANCE, REFURBISHMENT
● READY STANDBY & STORAGE
LOGISTICS
FACILITIES
DSARC REVIEW
DSARC REVIEW
SHUTTLE PAYLOAD IOC (REF)
DSARC REVIEW
DSARC REVIEW
FSDP ATP
INCR I FLT TEST
INCR I IOC JUN 1981
INCR II FLT TEST
INCR II IOC 31 DEC 83
PDR
CDR
PDR
CDR
ENGINE CONTRACTOR ATP
DF
STV
IVU
IATU
STV
DF
IATU
PTV
LO
FO
LO
FO
ETR
360 TOTAL FLIGHTS
2 INCR I DT & E FLIGHTS (NO PAYLOAD)
8 INCR I IOT & E FLIGHTS (NO PAYLOAD)
FV-1
INCR I IOC
84 INCR I OPNL FLTS
30.2 DAYS TURN AROUND PER VEHICLE
2 INCR II DT & E FLTS (NO PAYLOA
10 INCR II IOT & E FLIGHT (WITH PAYLOAD)
INCR II IOC
284 INCR II OP
ETR
WTR

production go-ahead in March 1980. Eight payload/IOT&E flights are completed over a 1.3 year period using flight vehicle number one. The first operational flights begin in June 1981 using production vehicles. Fifty four Increment I operational flights take place over a 2.5 year period, ending in December 1983.

Increment II payload flights being following Increment II DSARC III review and production go-ahead in March 1982. Ten payload/IOT&E flights are completed over a 1.8 year period using flight vehicle number one. The first operational flights begin on 31 December 1983 using production vehicles. Two hundred eighty four Increment II operational flights take place over a seven year period ending in December 1990.

5.7 COST SUMMARY (DOD ACQUISITION)

Summary cost data for this Program Option to be implemented in accordance with the DOD Acquisition Approach (AFSCP 800-3) are presented in the following charts:

A. Summary Cost Tabulations
B. Annual Funding
C. Cost Per Flight Data Sheets

Reference is made to Volume VIII, Book 3 for detail cost information.

The Summary Cost Tabulation (Table 5-13) is derived from the LEADER II Cost Model printout which is provided in Volume VIII, Book 3, Section 12. The Annual Funding chart (Table 5-14 and Figure 5-12) displays fiscal year funding requirements for the program by program phase and by agency (DOD/NASA). The Cost Per Flight Data Sheets (Tables 5-15 through 5-23) have been prepared in accordance with NASA direction (Reference: Letter PD-TUG-P(015-74), dated August 3, 1973, from J . A. Stucker, Manager, Program Planning and Control to A. G. Orillion, (COR,PD-TUG-C). No cost per flight data sheet has been provided for DOD flight mode two since DOD requires no flights in this mode. e cost per flight sheet for one DOD flight requiring an expended kick stage (mode 3) during the initial phase of the program has been included.

Table 5-13

PROGRAM OPTION 3 - DOD
SPACE TUG
COST SUMMARY TABULATION
1973 DOLLARS IN MILLIONS

	PROGRAM PHASE				
	VALIDATION	FULL SCALE DEVELOPMENT	PRODUCTION	OPERATIONS	TOTAL
DOD					
INITIAL	16.08	199.30	68.70	42.17	326.25
FINAL	23.52	107.14	141.05	95.32	367.03
TOTAL	39.60	306.44	209.74	137.49	693.28
NASA					
INITIAL	-----	17.39	12.19	26.79	56.37
FINAL	-----	12.36	4.97	99.91	117.24
TOTAL	-----	29.75	17.16	126.70	173.61
TOTAL PROGRAM	39.60	336.19	226.91	264.19	866.89

PROGRAM OPTION NO. 3 - DOD

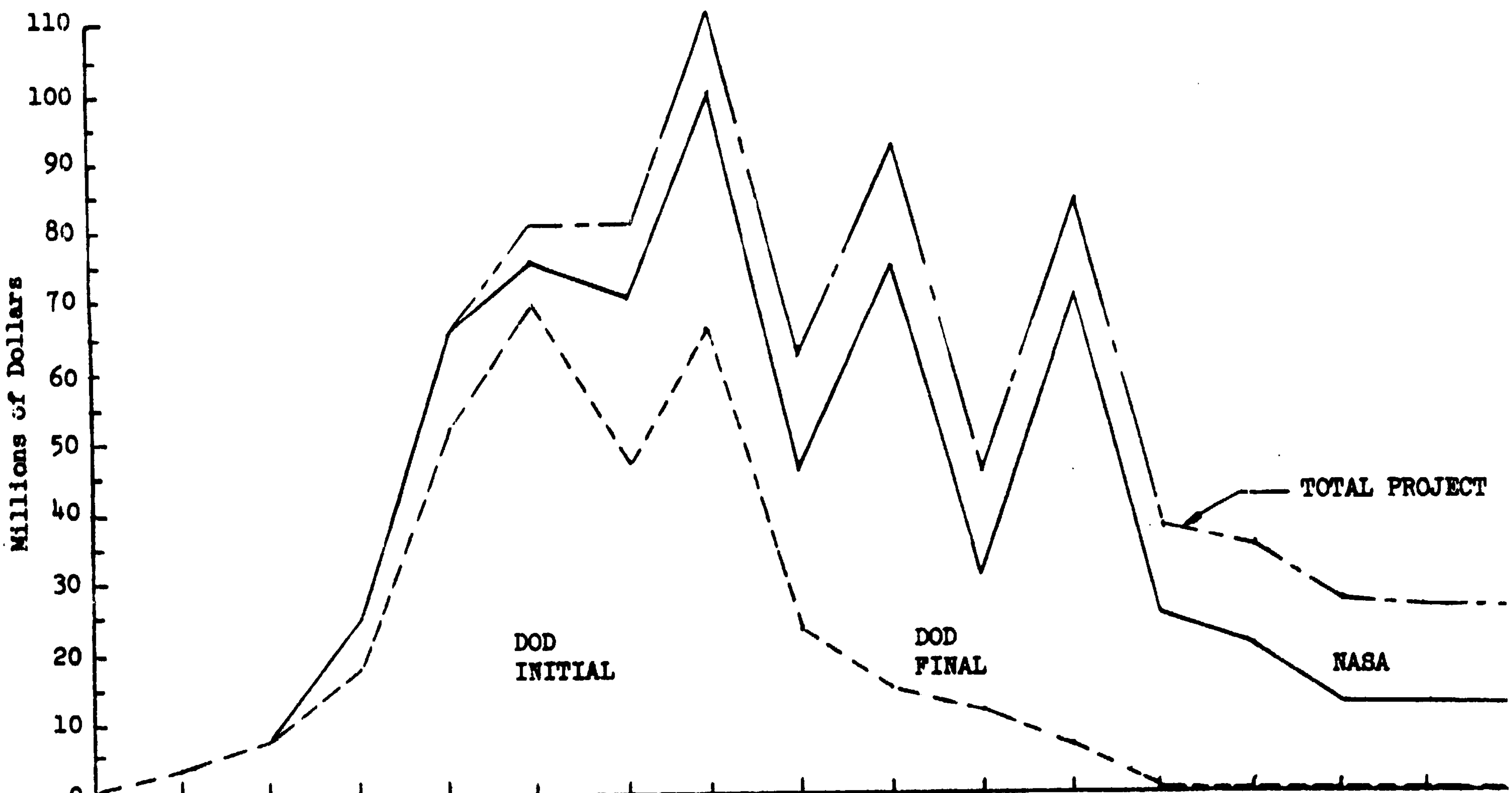
WBS 320 LEVEL - 3 T..AL SPACE TUG PROJECT

ANNUAL FUNDING - TABULAR

1973 DOLLARS IN MILLIONS

Y	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
DD ITIAL																	
VALID.	3.0	8.0	5.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FSD	0	0	12.9	52.4	69.5	41.7	18.1	4.7	.1	0	0	0	0	0	0	0	0
PROD	0	0	0	0	0	5.5	47.9	11.3	3.1	.4	.2	.2	.2	0	0	0	0
OPS	0	0	0	0	0	0	.8	7.7	11.6	12.3	6.4	.4	.4	.4	.4	.4	.4
UBTOTAL	3.0	8.0	18.0	52.4	69.5	47.2	66.8	23.7	14.8	12.7	6.6	.6	.6	.4	.4	.4	.4
DD INAL																	
VALID.	0	0	6.0	15.0	2.5	0	0	0	0	0	0	0	0	0	0	0	0
FSD	0	0	0	0	5.7	24.3	33.8	22.4	13.1	5.8	2.1	0	0	0	0	0	0
PROD	0	0	0	0	0	0	0	.1	53.8	13.0	55.1	10.8	8.2	0	0	0	0
OPS	0	0	0	0	0	0	0	0	0	0	6.9	13.8	13.8	13.8	13.8	13.8	13.1
UBTOTAL	0	0	6.0	15.0	8.2	24.3	33.8	22.5	66.9	18.8	64.1	24.6	22.0	13.8	13.8	13.8	13.1
OTAL	3.0	8.0	24.0	67.4	77.7	71.5	100.6	46.2	81.7	31.5	70.7	25.2	22.6	14.2	14.2	14.2	13.5
ASA NITIAL	0	0	0	0	3.0	9.1	9.2	12.6	9.0	9.0	4.5	0	0	0	0	0	0
ASA INAL	0	0	0	0	0	0	2.1	2.5	2.5	4.8	9.6	15.3	15.3	15.3	14.3	14.3	14.3
ASA OTAL	0	0	0	0	3.0	9.1	11.3	15.1	11.5	13.8	14.1	15.3	15.3	15.3	14.3	14.3	14.3
ROJECT	[illegible]	8.0	24.0	67.4	80.7	80.6	111.9	61.3	93.2	45.3	84.8	40.5	37.9	29.5	28.5	28.5	27.8

OPTION 3 DOD PROGRAM
ANNUAL FUNDING
(1973 Dollars in Millions)



GFY	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
D Initial	3.0	8.0	18.0	52.4	69.5	47.2	66.8	23.7	14.8	12.7	6.6	.6	.6	.4	.4	.4
D Final			6.0	15.0	8.2	24.3	33.3	22.5	66.9	18.8	64.1	24.6	22.0	13.8	13.8	13.8

Table 5-15
PROGRAM OPTION 3 - DOD
UNIT COST TABULATION
(1973 Dollars in Millions)

	3I-DOD	3F-DOD
Vehicle Main Stage		
First Unit Production Cost	$13.48	$15.94
Average Unit (Including Support)	13.74	12.82
Vehicle Auxiliary Stage		
Average Unit (Including Support	4.05	7.10

	3I-DOD	3F-DOD
Average Cost Per Flight		
Mode 1 NASA	1.023	0.683
Mode 1 DOD	1.033	0.702
Mode 2 NASA	14.396	13.295
Mode 2 DOD		
Mode 3 NASA	5.083	1.393
Mode 3 DOD	5.093	

Table 5-10 Average Cost per Flight

MODE 1 Reusable Basic Stage

		PROGRAM OPTION
LAUNCH OPERATIONS		$ 188,687
Tug/Shuttle mating and checkout	$ 19,242	
Tug/Payload mating and checkout	19,568	
Prelaunch checkout	23,917	
Countdown	31,150	
Propellant and gases	6,510	
Post flight safing	25,558	
Site services and support	62,742	
MAINTENANCE AND REFURBISHMENT		$ 366,908
Scheduled maintenance and refurbishment	$ 31,680	
Unscheduled maintenance and refurbishment	7,800	
Tug engine maintenance and refurbishment	21,515	
Tug vehicle spares	74,365	
Tug engine spares	19,298	
Post maintenance checkout	1,958	
Refurbishment requirements planning	8,843	
Depot maintenance	201,449	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 555,59[illegible]
FLIGHT OPERATIONS		$ 282,50[illegible]
Mission planning	$ 48,200	
Flight control	159,900	
Flight evaluation	43,600	
Flight software	30,800	
OPERATIONS SUPPORT		$ 184,9[illegible]
Airborne software update	$ 10,202	
GSE maintenance	45,602	
Sustaining engineering	40,685	
Program management	27,779	
Transportation and handling	1,229	
Inventory control and warehousing	12,783	
Facilities maintenance	14,873	
GSE software update	31,835	
EXPENDABLE VEHICLE MAIN STAGE		$ -0-

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AGENCY 909

PROGRAM OPTION 5?

Table 5-17 AVERAGE COST PER FLIGHT

/ Reusable Basic Stage

H ...ERATIONS		$ 191,081
g/Shuttle mating and checkout	$ 19,547	
g/Payload mating and checkout	19,731	
elaunch checkout	24,294	
untdown	31,665	
opellant and gases	6,391	
st flight safing	25,912	
te services and support	63,541	
ENANCE AND REFURBISHMENT		$ 365,064
heduled maintenance and refurbishment	$ 32,088	
scheduled maintenance and refurbishment	7,898	
g engine maintenance and refurbishment	21,107	
g vehicle spares	72,956	
g engine spares	18,932	
s aintenance checkout	2,046	
furbishment requirements planning	8,926	
pot maintenance	201,061	
GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 556,145
T OPERATIONS		$ 294,900
ssion planning	$ 49,100	
ight control	171,800	
ight evaluation	41,800	
ight software	32,200	
TIONS SUPPORT		$ 181,485
rborne software update	$ 10,009	
E maintenance	44,738	
staining engineering	39,915	
ogram management	27,253	
a portation and handling	1,206	
ventory control and warehousing	12,541	
cilities maintenance	14,591	
E software update	31,232	
DABLE VEHICLE MAIN STAGE		$ 0

:DE 1 Reusable Basic Stage		PROGRAM OPTION
LAUNCH OPERATIONS		$ 203,388
Tug/Shuttle mating and checkout	$ 19,375	
Tug/Payload mating and checkout	24,265	
Prelaunch checkout	23,059	
Countdown	37,575	
Propellant and gases	6,427	
Post flight safing	27,189	
Site services and support	65,068	
MAINTENANCE AND REFURBISHMENT		$ 207,521
Scheduled maintenance and refurbishment	$ 34,439	
Unscheduled maintenance and refurbishment	6,729	
Tug engine maintenance and refurbishment	9,143	
Tug vehicle spares	30,905	
Tug engine spares	3,723	
Post maintenance checkout	1,723	
furbishment requirements planning	8,219	
Depot maintenance	112,640	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 410,909
FLIGHT OPERATIONS		$ 186,800
Mission planning	$ 40,100	
Flight control	81,500	
Flight evaluation	44,900	
Flight software	20,300	
OPERATIONS SUPPORT		$ 84,882
Airborne software update	$ 10,079	
GSE maintenance	1,054	
Sustaining engineering	25,040	
Program management	20,790	
Transportation and handling	807	
Inventory control and warehousing	14,434	
Facilities maintenance	-0-	
GSE software update	12,678	
EXPENDABLE VEHICLE MAIN STAGE		$ -0-
		-0-

Table 5-19 . AVERAGE COST PER FLIGHT

AGENCY DoD

PROGRAM OPTION EF D[illegible]

Reusable Basic Stage

OPERATIONS		$ 195,400
Shuttle mating and checkout	$ 18,467	
Payload mating and checkout	23,268	
aunch checkout	22,102	
tdown	36,109	
ellant and gases	6,468	
flight safing	26,202	
services and support	62,784	
ANCE AND REFURBISHMENT		$ 211,339
duled maintenance and refurbishment	$ 33,008	
heduled maintenance and refurbishment	6,435	
engine maintenance and refurbishment	9,202	
vehicle spares	31,103	
ine spares	3,747	
maintenance checkout	1,651	
rbishment requirements planning	7,869	
t maintenance	118,321	
ROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 406,739
		$ 209,600
OPERATIONS		
sion planning	$ 49,400	
ght control	82,000	
ght evaluation	55,400	
ght software	22,800	
IONS SUPPORT		$ 85,427
borne software update	$ 10,144	
maintenance	1,060	
taining engineering	25,200	
m management	20,924	
nsportation and handling	813	
entory control and warehousing	14,527	
ilities maintenance	-0-	
software update	12,759	
		-0-

Table 5-20 AVERAGE COST PER FLIGHT — AGENCY NASA

MODE 2 EXPENDED TUG — PROGRAM OPTION

LAUNCH OPERATIONS		$ 203,358
Tug/Shuttle mating and checkout	$ 19,375	
Tug/Payload mating and checkout	27,265	
Prelaunch checkout	23,029	
Countdown	37,575	
Propellant and gases	6,427	
Post flight safing	27,189	
Site services and support	65,468	
MAINTENANCE AND REFURBISHMENT		$ 0
Scheduled maintenance and refurbishment	$	
Unscheduled maintenance and refurbishment		
Tug engine maintenance and refurbishment		
Tug vehicle spares		
Tug engine spares		
Post maintenance checkout		
Refurbishment requirements planning		
Depot maintenance		
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 203,358
FLIGHT OPERATIONS		$ 186,800
Mission planning	$ 40,100	
Flight control	81,500	
Flight evaluation	44,900	
Flight software	20,300	
OPERATIONS SUPPORT		$ 84,882
Airborne software update	$ 10,079	
GSE maintenance	1,054	
Sustaining engineering	25,040	
Program management	20,770	
Transportation and handling	807	
Inventory control and warehousing	14,434	
Facilities maintenance	0	
GSE software update	12,678	
EXPENDABLE VEHICLE MAIN STAGE		$ 12,820,0[illegible]

Table 5-2. AVERAGE COST PER FLIGHT — AGENCY

3 EXPENDED KICKSTAGE — PROGRAM OPTION 3

I ERATIONS		$ 188,687
;/Shuttle mating and checkout	$ 19,242	
;/Payload mating and checkout	19,568	
:launch checkout	23,917	
ıntdown	31,150	
›pellant and gases	6,510	
ıt flight safing	25,558	
:e services and support	62,742	
:NANCE AND REFURBISHMENT		$ 366,908
ıedııled maintenance and refurbishment	$ 31,680	
ıcheduled maintenance and refurbishment	7,800	
; engine maintenance and refurbishment	21,515	
; vehicle spares	74,365	
; engine spares	19,298	
ı aintenance checkout	1,958	
ˈurbishment requirements planning	8,843	
›ot maintenance	201,444	
GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 555,595
' OPERATIONS		$ 282,500
ısion planning	$ 48,200	
ght control	159,900	
ght evaluation	43,600	
ght software	30,800	
'IONS SUPPORT		$ 184,958
ˈborne software update	$ 10,202	
; maintenance	45,602	
ıtaining engineering	40,685	
ıgram management	27,779	
; ortation and handling	1,229	
ˈentory control and warehousing	12,783	
:ilities maintenance	14,873	
; software update	31,835	

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DE 3 EXTENDED KICKSTAGE		PROGRAM OPTION
		$ 191,081
LAUNCH OPERATIONS		
Tug/Shuttle mating and checkout	$ 19,547	
Tug/Payload mating and checkout	19,731	
Prelaunch checkout	24,294	
Countdown	31,665	
Propellant and gases	6,391	
Post flight safing	25,912	
Site services and support	63,541	
MAINTENANCE AND REFURBISHMENT		$ 365,064
Scheduled maintenance and refurbishment	$ 32,088	
Unscheduled maintenance and refurbishment	7,898	
Tug engine maintenance and refurbishment	21,107	
Tug vehicle spares	72,956	
Tug engine spares	18,932	
Post maintenance checkout	2,096	
Refurbishment requirements planning	8,926	
Depot maintenance	201,061	
TOTAL GROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 556,145
		$ 294,900
FLIGHT OPERATIONS		
Mission planning	$ 49,100	
Flight control	171,800	
Flight evaluation	41,800	
Flight software	32,200	
OPERATIONS SUPPORT		$ 181,185
Airborne software update	$ 10,009	
GSE maintenance	44,738	
Sustaining engineering	39,915	
Program management	27,253	
Transportation and handling	1,206	
Inventory control and warehousing	12,541	
Facilities maintenance	14,591	
GSE software update	31,232	
		$ -0-
EXPENDABLE VEHICLE MAIN STAGE		

Table 5-23 AVERAGE COST PER FLIGHT

AGENCY [illegible]

PROGRAM OPTION [illegible]

3 EXPENDED KICKSTAGE

OPERATIONS		$ 203,388
'Shuttle mating and checkout	$ 19,375	
'Payload mating and checkout	24,265	
.aunch checkout	23,089	
ıtdown	37,575	
pellant and gases	6,427	
; flight safing	27,189	
: services and support	65,468	
IANCE AND REFURBISHMENT		$ 207,521
:duled maintenance and refurbishment	$ 34,439	
:heduled maintenance and refurbishment	6,729	
engine maintenance and refurbishment	9,143	
vehicle spares	30,905	
engine spares	3,723	
; [illegible]intenance checkout	1,723	
ırbishment requirements planning	8,219	
ɔt maintenance	112,640	
:ROUND OPERATIONS (Launch and Maintenance and Refurbishment)		$ 410,909
OPERATIONS		$ 186,800
ıion planning	$ 40,100	
;ht control	81,500	
;ht evaluation	44,900	
;ht software	20,300	
IONS SUPPORT		$ 84,882
ɔorne software update	$ 10,079	
maintenance	1,054	
;aining engineering	25,040	
;r[illegible] management	20,790	
ısportation and handling	807	
:ntory control and warehousing	14,434	
ilities maintenance	0	
software update	12,678	

5.8 PROGRAM MANAGEMENT FOR THE SPACE TUG PROJECT

MDAC-W's management approach on the Space Tug Project is to apply the tools and techniques most appropriate to ensure project control at an acceptable cost level. Out approach includes reaffirming the government amanagement requirements so that we can be appropriately responsive to their needs. MDAC-W's available management tools and techniques have evolved during extensive development and use with both NASA and DOD programs as well as on Douglas commercial aircraft programs.

As demonstrated during the Space Tug Phase A Systems Study, the MDAC-W management philosophy emphasizes "cost planning". This cost planning, which will continue throughout all phases of program definition and beyond, will result in cost awareness/cost avoidance attitudes that are essential to effective project cost control. This cost planning is not limited to just the prime contractor role but will extend through the working relationships to the government and to the suppliers to establish clear-cut cost objectives and th management plans appropriate for achieving these objectives.

MDAC-W's cost-awareness/cost avoidance philosophy on Space Tug emphasizes the identification of and the avoidance of all unnecessary costs. This will call for close contractor/government working relationships and teamwork to define and manage to only those effective project requirements. The net effect of the application of this philosophy is to develop the Space Tug with only the necessary equipment, material, and labor, and hence at lower costs.

Actions that are highlights of the MDAC-W low-cost management approach on Space Tug include:

A. Develop (in concert with the customer) well-defined mission performance parameters and cost objectives early in DDT&E.
B. Assign highly capable personnel with applicable experience.
C. Develop well defined program plans based upon essential technical anc management requirements to accomplish the mission. These program

D. Provide closely coupled contractor/government working relationship including co-location of counterparts and task-sharing where effective.

F. Develop specific contractual clauses that provide motivation to both contractor and government to achieve lowest cost consistent with excellence of performance and tight schedule requirements.

F. Operate critical change control under strict criteria (is it functionally necessary—is it cost-effective) for accept/reject decision.

G. Apply management systems responsive to the needs of contractor/government and provide timely visibility into potential problem areas to avoid vulnerability to unplanned cost or schedule delays.

H. Procure "buy" items, particularly off-the-shelf material and subsystems components, from lowest cost, technically capable suppliers.

Features of several of the more crucial management systems are presented below:

A. Performance Measurement System (PMS)—The MDAC PMS is an on-line approved system currently in use on the Air Force ACE program, the Army SAFEGUARD/Spartan and Site Defense programs, and the Navy Harpoon program. Our experiences show that a low-cost and effective PMS requires a realistic WBS structure, ability to selectively apply BCWS/BCWP and variance analyses, ability to adjust the levels of reporting and control to the magnitude of the cost risk represented by the WBS element, and to provide management reports at meaningful time intevals.

B. Cost-Per-Flight (CPF) Management Controls—CPF controls have been developed that are closely integrated with the PMS and the change control system. Based upon MCAD's life-cycle-cost-modeling technology, CPF provides cost goals (targets) throughout the WBS. CPF provides continuing predictive capability for total cost and CPF, impact assessment, and variance projections against lower level WBS element fully accountable for successful attainment of CPF goals including development of the options and trade analyses necessary to recover should unfavorable variances appear. One of the keys to achieving low-cost objectives is to understand the impact of decisions of program costs—a primary purpose of CPF.

C. Configuration and Change Management (CM)—The goal of CM is to effectively define contract item configuration and to manage change. On Space Tug, it is imperative that once a configuration is defined that strict criteria, by which a proposed change can be evaluated and accepted/rejected rapidly and effectively, be established. The configuration control board chaired by the program manage will use the CPF analysis to know the impact of changes against the CPF targets and the cost budgets. There is a corollary to the use of strict change criteria which implies that to avoid unnecessary costs the mission requirements are well defined and that the design team can design it right the first time to minimize changes.

D. Information Management (IM)—The most effective as well as lowest cost IM system is one that makes maximum use of informal direct communication between designated contractor/government counterparts for daily decision-making. This informal interchange is backed up by the formal contractual reporting system which provides documentation of the key data and decision/action items for historical reference. The contracted data procurement document (DRD) and data requirements list (DRL) will make maximum use of internal data wherever possible. In addition, MDAC accessioning and deferred delivery methods will offer the customer up-to-date information on available internal documentation while minimizing the need for routine submission of data.

E. Procurement Management—MDAC approach to make-or-buy, source selection, and procurement is to make use of existing proven industry capabilities, while maintaining focus on the CPF targets. CPF and CPF project reviews with a minimum of reprocessing. In accord with our internal information management systems, the customer will have direct access to subcontractor/supplier data.

F. Engineering Management—MDAC design team has extensive and successful cryogenic launch vehicle experience. A single organization will perform analyses. integration, and design tasks supported by functional specialists, as required, (tooling, manufacturing, qualify, test, logistics, etc.) who are involved from project inception. Supporting this multi-discipline team approach is the recommendation for co-locating contractor/customer/supplier representatives to encourage face-toface daily dialogue. Cost-per-flight targets are assigned down to the lowest practical level of the WBS and the design team will have specific Design-to-Cost (DTC) training. As the design concept evolves, senior engineers will be part of the team who will review the mission requirements, the design requirements, the detailed specifications, and the design drawings to ensure a thorough evaluation of alternatives to emphasize low-life-cycle costs, standard parts, and off-the-shelf hardware. Critical technical performance perameters, e.g., CPF, are selected for status reporting to provide most meaningful technical progress assessment. Parameters are tracked by time-dependent trend data or single-point events and are measured by analysis or test will variances reported in time for corrective action with minimum cost/schedule impact. In addition to the above, the Engineering and the Manufacturing releases are closely coordinated (jointly signed off) before release to ensure full understanding and communication of each others requirements and intentions.

In summary, application of MDAC cost awareness/cost avoidance philosophy will enable Space Tug to avoid unnecessary material and labor costs. We will:

A. Understand the essential mission and program requirements, specifically:

B. Design and manage to meet the essential life-cycle requirements and the CPF targets.

C. Test to verify design but minimize test hardware requirements and testing activities.

5.9 SUPPORTING RESEARCH AND TECHNOLOGY SUMMARY (SR&T)

The SR&T requirements for Option 3 are shown in Table 5-24.

The first item, development of potential hazard/failure detection technique relates to safety and is applicable to any Tug program, regardless of fundi constraints or phasing. The second item relates to establishing basic data required to develop an effective thermal control system. The dollars shown are a summation of the thermal control requirements for both the initial an final configurations. The remaining items in the avionics area are require for the final configuration. In the G&C area, star tracker self-check and IMU self-calibration are needed to reduce maintenance costs. Laser radar rendezvous/docking techniques need substantial advancement before final difinition for the Tug. Performance is the primary offshoot of improving fuel cell specifics.

The SR&T for the option represents just over 5 percent of total program DDT

5.10 RISK ASSESSMENT SUMMARY PHASED PROGRAM OPTION 3

The Space Tug project is in the early stages of program definition (Phase A We are confident that as definition of the hardware, software, and programmatics evolve, that the risk values identified will diminish significantly. Therefore, we assess Program Option 3 as a moderately low risk program.

On a scale of 0 to 10 (i.e., low risk to high risk, respectively) the avera life-cycle risk values for Options 3 initial/3 Final are: 2.4/2.5 for Cost; 2.0/2.4 for Schedule; and 2.7/3.1 for Technical performance. (Refer to RIS ASSESSMENT SUMMARY Tables 5-25 through 5-31. These relatively low risk val mean that the multi-discipline team of experts, who have assessed the uncert

Table 5-24

SR&T SUMMARY - OPTION 3

WBS Element/Option	Technology Requirement	Cost ($M)	Time (Years)	Required Start Time
320-03 Vehicle Main Stage	Develop potential hazard/failure detection techniques	0.75	1.5	CY 1/75
320-03-02 Thermal Control Radiation Barrier Multi-Layer Insulation	Establish thermal performance, material properties and purge bag material, fabrication, and operation techniques	0.24	1.5	7/75
320-03-03 Avionics - GN&C	Increase star tracker/horizon sensor self-check capability	3.00	1.5	4/78
	Add IMU self-calibration capability	2.00	1.5	4/78
Rendezvous/Docking	Develop laser radar rendezvous/docking techniques	5.00	2.0	10/77
Power	Reduce fuel cell weight, increase efficiency, life	3.00	1.0	10/78
	TOTAL	13.99		

Table 5-25

RISK ASSESSMENT SUMMARY PROGRAM OPTION 3I

Risk Values (0 = Low; 10 = High Risk)

Project Phase	Risk Area		
	Cost	Schedule	Technical
DDT&E	2.9	1.9	3.2
PROD	2.2	1.7	2.4
OPNS	2.1	2.3	2.6
Average Life Cycle Risk Values	2.4	2.0	2.7

Table 5-26

RISK ASSESSMENT DATA SHEET

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	3	1	1	
320-02 Systems Engr and Integration	3	1	1	
320-03 Vehicle Main Stage				
-01 Structures	2	2	4	
-02 Thermal Control	2	2	4	
-03 Avionics	2	2	3	
-04 Propulsion	2	1	4	
-05 Orbiter Interface	5	1	6	Prelim spec definition (cost); prelim abort data and analysis (tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Assy & C/O	2	2	5	Pressure/chemical/heat hazards (tech)
320-04 Vehicle Auxiliary Stage	5	GFE	1	Mfg start-up on Poseidon questionable (cost)
320-05 Logistics	3	3	1	

Table 5-26

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 3I, DDT&E Phas
Page 2 of

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-06 Facilities	5	3	1	Prelim info only (cost)
320-07 Ground Support Equipment	3	2	5	Prelim Definition of interfaces (tech)
320-08 Vehicle Test	3	2	4	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	2	3	2	
320-12 Flight Opns - ETR	2	3	2	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	44	28	48	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	2.9	1.9	3.2	

Table 5-27

RISK ASSESSMENT DATA SHEET

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	2	1	1	
320-02 Systems Engr and Integration	2	1	1	
320-03 Vehicle Main Stage				
-01 Structures	2	2	4	
-02 Thermal Control	2	2	1	
-03 Avionics	2	2	3	
-04 Propulsion	2	1	3	
-05 Orbiter Interface	3	1	5	Prelim spec definition (tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	2	2	5	Pressure/chemical/heat hazards (tech)
320-04 Vehicle Auxiliary Stage	5	GFE	1	Mfg start-up on Poseidon questionable (cost)
320-05 Logistics	2	3	1	

Table 5-27

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 3I, PROD P

Page 2 (

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greate
320-06 Facilities	1	3	1	
320-07 Ground Support Equipment	1	2	3	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	-	-	-	
320-12 Flight Opns - ETR	-	-	-	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	26	20	29	
MAXIMUM SCORE POSSIBLE	120	120	120	
RISK VALUE (0-10 SCALE)	2.2	1.7	2.4	

Table 5-28

RISK ASSESSMENT DATA SHEET

Program Option 3I, OPNS Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	-	-	-	
320-02 Systems Engr & Integration	-	-	-	
320-03 Vehicle Main Stage				
-01 Structures	1	2	1	
-02 Thermal Control	1	2	4	
-03 Avionics	1	2	3	
-04 Propulsion	1	1	3	
-05 Orbiter Interface	1	1	1	
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	N/A	N/A	N/A	
320-04 Vehicle Auxilary Stage	1	GFE	2	
-05 Logistics	2	3	1	
320-06 Facilities	3	3	1	

Table 5-28

RISK ASSESSMENT DATA SHEET (Continued)

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater
320-07 Ground Support Equipment	2	2	1	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	3	3	4	
320-10 Launch Opns - ETR	3	3	4	
320-11 Flight Opns - WTR	3	3	4	
320-12 Flight Opns - ETR	3	3	4	
320-13 Refurb & Integration - WTR	3	3	3	
320-14 Refurb & Integration - ETR	3	3	3	
TOTAL SCORE	31	34	39	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	2.1	2.3	2.6	

Table 5-29

RISK ASSESSMENT SUMMARY PROGRAM OPTION 3F

Risk Values (0 = Low; 10 = High Risk)

Project Phase	Risk Area		
	Cost	Schedule	Technical
DDT&E	3.0	2.3	3.3
PROD	2.3	2.2	3.0
OPNS	2.1	2.6	2.9
Average Life Cycle Risk Values	2.5	2.4	3.1

Table 5-30

RISK ASSESSMENT DATA SHEET

Program Option 3F, DDT&E P
Page 1

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greate
320-01 Project Management	3	1	1	
320-02 Systems Engr and Integration	3	1	1	
320-03 Vehicle Main Stage				
-01 Structures	2	3	4	
-02 Thermal Control	2	3	4	
-03 Avionics	3	3	7	Laser docking/advance cell/solid state power distribution (tech)
-04 Propulsion	2	2	4	
-05 Orbiter Interface	5	1	6	Prelim spec definition (cost); prelim abort d and analysis (tech)
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	2	3	6	Pressure/chemical/heat hazards (tech)
320-04 Vehicle Auxiliary Stage	5	GFE	1	Mfg start-up on Poseid questionable (cost)
320-05 Logistics	3	3	1	

Table 5-30

RISK ASSESSMENT DATA SHEET (Continued)

Program Option 3F, DDT&E Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-06 Facilities	5	3	1	Prelim info only (cost)
320-07 Ground Support Equipment	3	3	5	Prelim definition of interfaces (tech)
320-08 Vehicle Test	3	3	2	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	2	3	3	
320-12 Flight Opns - ETR	2	3	3	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	45	35	49	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	3.0	2.3	3.3	

Table 5-30

RISK ASSESSMENT DATA SHEET (Continued)

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater
320-06 Facilities	1	3	1	
320-07 Ground Support Equipment	1	3	4	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	-	-	-	
320-10 Launch Opns - ETR	-	-	-	
320-11 Flight Opns - WTR	-	-	-	
320-12 Flight Opns - ETR	-	-	-	
320-13 Refurb & Integration - WTR	-	-	-	
320-14 Refurb & Integration - ETR	-	-	-	
TOTAL SCORE	27	26	36	
MAXIMUM SCORE POSSIBLE	120	120	120	
RISK VALUE (0-10 SCALE)	2.3	2.2	3.0	

Table 5-31

RISK ASSESSMENT DATA SHEET

Program Option 3F, OPNS Phase

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater)
320-01 Project Management	-	-	-	
320-02 Systems Engr and Integration	-	-	-	
320-03 Vehicle Main Stage				
-01 Structures	1	3	1	
-02 Thermal Control	1	3	4	
-03 Avionics	1	3	4	
-04 Propulsion	1	2	3	
-05 Orbiter Interface	1	1	1	
-06 Drop Tanks	N/A	N/A	N/A	
-07 Final Ass'y & c/o	N/A	N/A	N/A	
320-04 Vehicle Auxiliary Stage	1	GFE	2	
0-05 Logistics	2	3	1	
320-06 Facilities	3	3	1	

Table 5-31

RISK ASSESSMENT DATA SHEET (Continued)

Program Option, 3F, OPNS P
Page 2

WBS Element	Risk Values 0 = Low; 10 = High Cost	Sched	Tech	Risk Assessment (Values of 5 or Greater
320-07 Ground Support Equipment	2	3	4	
320-08 Vehicle Test	-	-	-	
320-09 Launch Opns - WTR	3	3	4	
320-10 Launch Opns - ETR	3	3	4	
320-11 Flight Opns - WTR	3	3	4	
320-12 Flight Opns - ETR	3	3	4	
320-13 Refurb & Integration - WTR	3	3	3	
320-14 Refurb & Integration - ETR	3	3	3	
TOTAL SCORE	31	39	43	
MAXIMUM SCORE POSSIBLE	150	150	150	
RISK VALUE (0-10 SCALE)	2.1	2.6	2.9	

in accomplishing the cost, schedule, and technical objectives and assigned the risk values, have a moderately high degree of confidence that all objectives will be met for every WBS element in every phase of the project. Their collective judgments are based on the following:

A. Specifications on similar hardware and software items are available;

B. The hardware and software subsystems/components are well within the state-of-the-art and (as a minimum) prototype items have been produced (in many cases off-the-shelf hardware is selected);

C. The estimating ground rules and assumptions were generally adequate although subject to some question; and

D. The data have generally been obtained from reliable sources.

NOTE: A full description of our risk assessment methodology and the detailed data sheets are contained in Section 9 of Volume 8.

In the risk Assessment Data Sheets a narrative risk assessment is provided for all cost, schedule, and technical risk values of 5 or greater. It is significant that most of the moderate to high risk values shown are due to the preliminary or incomplete nature of the information available and are not due to technical or capability uncertainties. Therefore, as further definition of the program evolves, we can expect a corresponding decrease in all risk values.

6.1 3,500 LB RETRIEVAL CAPABILITY - OPTION 3S

This sensitivity study considered the impact on the final configuration of Option 3 of increasing the retrieval payload capability to 3,500 pounds. Th analysis was carried out assuming the initial configuration remains the same as in the normal Option 3 program.

6.1.1 Design Changes

Consideration of possible changes which could provide the increased performa led to the conclusion that any changes must include an increased ISP engine that the introduction of the RL10 CAT. IIA engine (with necessary accommoda tion changes) is sufficient to meet the performance requirement. The change are identified in assessing the propulsion system change to the CAT. IIA RL1 main engine. There are two primary changes: the main engine and the size o the main engine feedlines must be increased. With the new engine which oper at lower inlet pressures, the pressurization system can be eliminated allowi additional performance (and some cost savings).

The change of the feedlines results in minor structural to increase the size of the propellant tank sumps to accommodate the larger lines. Elimination o the pressurization system also eliminates supporting structural members.

6.1.2 Performance Impact

The design changes result in a burnout weight decrease of about 186 pounds a the engine change increases ISP by 17.4 seconds.

Based on the foregoing data, the geosynchronous orbit performance capabiliti were determined at the nominal 5.5:1 EMR and are presented by offloading LO_2 only on the round trip and deployment missions, an EMR of 5.0 could be used yielding a three second increase in ISP and the payloads shown in parenthese The corresponding performance for option 3F is shown also for comparison.

Geosynchronous Performance

	Option 3S	Option 3F
Deploy	6495 (6738)	4140 (4350)
Retrieve	4135	2455

6.1.4 Mission Accomplishment

Assessment of the capability of the 3S program to accomplish the Option 3S mission model was done by performing a complete capture analysis as reported in Volume 4, Supplement to Book 3. To perform the missions 332 flights are required as compared to 366 flights for the baseline Option 3. Also there are 9 additional missions in the Option 3S mission model (both Option 3 and 3S do not perform 32 of the missions because of shuttle limitations on the number of tug flights in 1980 and 1981). The fleet size is 15 vehicles, one less than was required in the baseline Option 3 program.

6.1.5 Test Program

The change of engine from a Category I to Category IIA RL10 engine results in a requirement for complete propulsion system qualification through a static firing sequence which simulates as close as possible to total design mission profile. This test program addition will involve a propulsion test vehicle (additional hardware). The propulsion test vehicle is not truly a vehicle, i.e., a Space Tug. The testing is concerned with the development and functional qualification of the main engine support assembly and associated interfaces only. The components which comprise the assembly either will have been developed and qualified on previously, except for the increased size feed lines which will be qualified during these tests.

6.1.6 Program Cost

The major impact upon program cost is the addition in DDT&E costs of the CAT. IIA RL10 main engine itself. This amounts to $50 million ($50 million as compared to $13 million for the CAT. I RL10 used on the baseline Option 3 configuration). Other DDT&E cost difference items include the feed lines (+ $0.8 million) and the lack of a requirement for a pressurization system (- $3.2 million).

The total program costs only changes an insignificant amount since the savings in the operations cost (due to less flights) offsets the increased DDT&E. However, the operations costs (see Table 6-1) do not include the Shuttle operations costs. If the Shuttle operations costs were included at $10.5 million per flight ($357 million) the

Table 6-1

OPTION 3S COST DIFFERENCES

		Δ COST ($ MILLIONS)
DDT&E		
ENGINE		+ 50.00
FEED SYSTEM		+ 0.80
STATIC FIRING TEST (PTV)		+ 5.33
PRESSURIZATION		- 3.20
	TOTAL	+ 52.93
PRODUCTION		
1 LESS TUG		- 15.0
10 LESS PRESSURIZATION SYSTEM		- 0.3
	TOTAL	- 15.3
OPERATIONS		
34 LESS FLIGHTS	34 X .98 =	- 33.2
	TOTAL	- 33.2
TOTAL PROGRAM		+ 4.43

6.2 TWO YEAR IOC DELAYS - INITIAL AND FINAL

The objective of this analysis was to determine the programmatic sensitivity of Option 3 to a two year IOC delay from December 31, 1979 to December 31, 1981, for the Initial phase of the project and from December 31, 1983 to December 31, 1985, for the Final phase. Primary goals were to evaluate techniques for reduc the peak year funding without excessive total program and early year DDT&E cost impact.

For this analysis, similar to Case 1 examined for Option 1 and reported in dete in Volume 8, Book 1, Section 8, it was assumed that the ATP for the Initial pha DDT&E was held at October 1975, as in the baseline option. Thus, an attempt wa made to trade schedule years against related cost impacts. The Initial phase DDT&E is extended by 21 months with resulting impacts on cost. By delaying the IOC two years, the Initial phase of the program loses 24 flights which decrease operations costs; however, delay of the Final phase causes the initial vehicle to fly significantly more missions in years 1984 and 1985, including 2 expendat missions. The net result of the operations difference amounts to a $1.8 milli increase in operations phase costs for the total project.

Figure 6-1 presents the planned project summary schedule for the IOC change and reflects the lengthened activity spans and milestone adjustments. Production of fleet vehicles is planned at a rate of 2.8 per year with a single shift work week.

Figure 6-2 presents a summary of the IOC delay impact on total project costs and funding. Peak annual funding for the initial phase is reduced, but the phase shifting of funding distribution produces a coupling effect between Initial and Final phase cost increases, resulting ultimately in a higher peak funding for the IOC delay of $83.4 million in FY 1981, and a second peak in F 1985 of $99.7 million. The delayed IOC program total cost is $918 million compared to the baseline $847 million. The only real advantages observed are decreased funding requirements in the early years of the program.

6.3 SENSITIVITY STUDY SUMMARY

The balance of the sensitivity studies which are summarized in Table 6-2 are discussed in detail in Volume 5.

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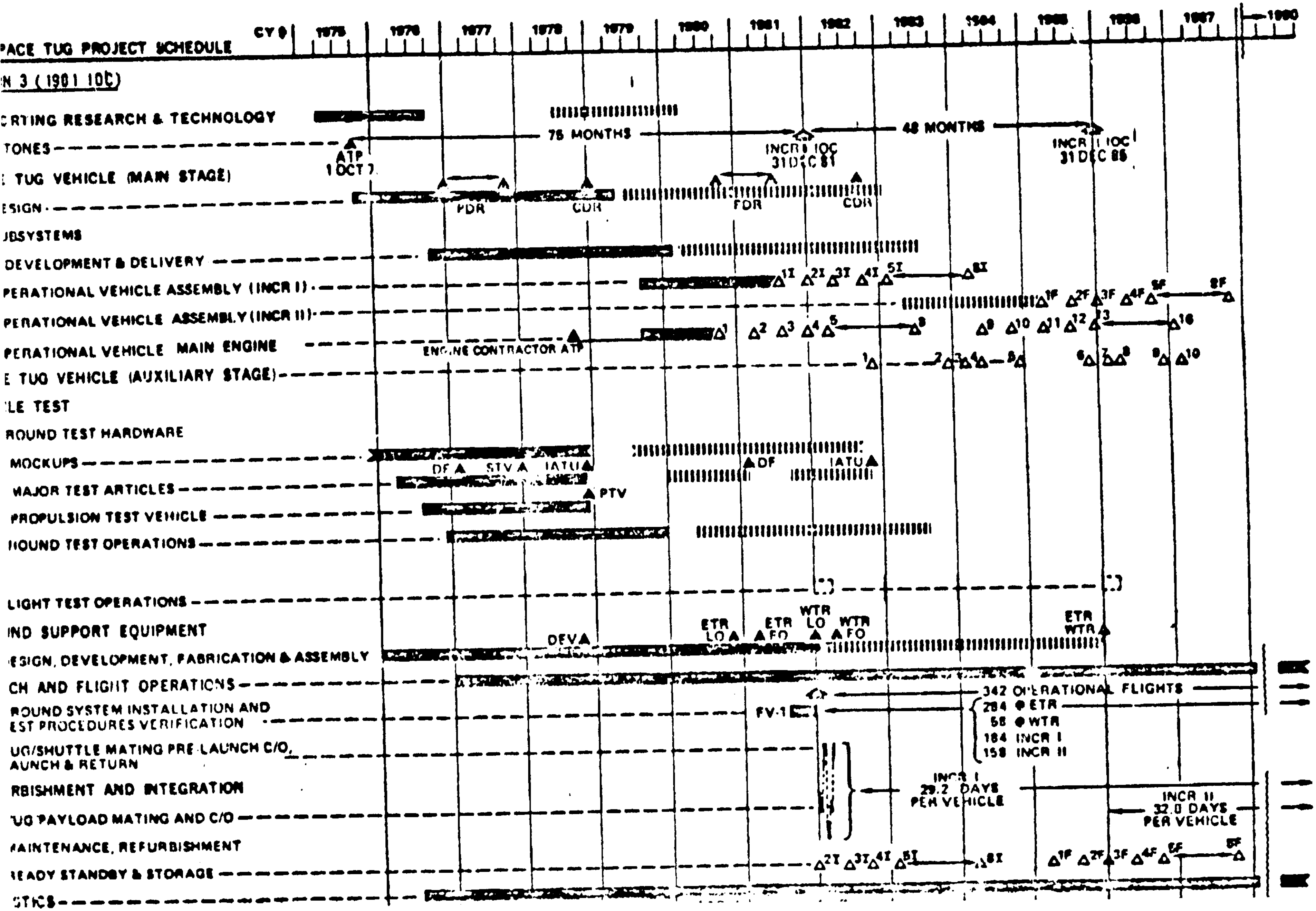

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Figure 6-2 PROGRAM OPTION NO. 3

2 YEAR DELAYED IOC - TOTAL PROJECT FUNDING IMPACT

ANNUAL FUNDING 1973 DOLLARS IN MILLIONS

REPLACEMENT PAGE
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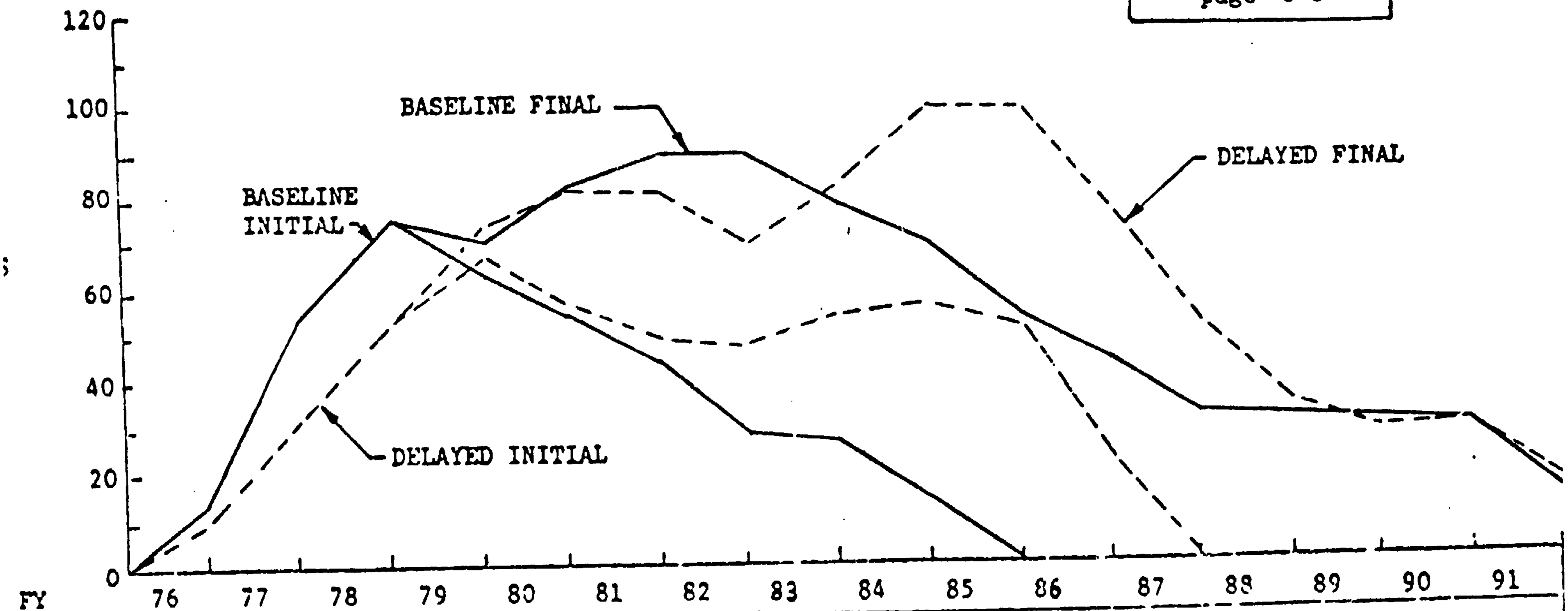

Table 6-2

SENSITIVITY RESULTS SUMMARY - OPTION 3F

		Impact Delta (Reference)							
		Cost ($ Millions)				Veh Design			
Sensitivity Area	Reference	Tech	DDT&E	First Unit	Total Opn	Inert Wt (Lb)	P/L Wt (Lb)	Dev Risk	Critical Tech Areas
Autonomy	Level III								
Level IV		0	-9.76	0	4.26			None	None
Level II		0	18.88	0.79	2.41			Medium	Auto Nav and Mission Plan
Level I		0	14.58	0.79	1.13			Low to Med	Auto Nav
0.97 Reliability	0.97/36 hr (I) 0.97/144 hr (F)								
0.97/36 hour		0	-3.4	-0.66	---	-36	+100	None	None
0.97/72 hour		0	0	-0.20	---	-10	+27	None	None
Design Life 100	20 flights	0	0	0	0	0	0	None	None